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THE

PRACTICAL RAILWAY ENGINEER.

EXAMPLES

OF THE

MECHANICAL AND ENGINEERING OPERATIONS AND STRUCTURES

COMBINED IN THE MAKING OF A RAILWAY.

I. CURVES, GRADIENTS, GAUGE, AND SLOPES.

II. EARTH-WORKS, CUTTINGS, EMBANKMENTS, AND DRAINS.

III. RETAINING WALLS, BRIDGES, TUNNELS, &c.

IV. PERMANENT WAY AND CONSTRUCTION.

V. STATIONS AND THEIR FITTINGS, LOCOMOTIVE POWER AND ALL ARRANGEMENTS BELONGING THERETO, CARRIAGES, &c.

WITH FIFTY ENGRAVINGS.

BY G. DRYSDALE DEMPSEY, C.E.

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RAILWAYS.

In the series of Papers of which this is the first, it is proposed to offer a condensed account of the engineering and mechanical operations and structures which are combined in the making and equipment of a railway.

To do this as efficiently as the limits of the allotted space will allow, it is proposed to select examples from works already executed, presenting a useful collection of materials and facts, arranged so as to be adapted for ready application by Royal Engineers and others on whom may devolve the conduct of similar works at home and abroad.

Without any pretensions to a complete history of any individual railway, the work will aspire to the character of such a record as will assist an engineer in applying his professional knowledge, with readiness and certainty, in the design and execution of the works required for any line committed to him.

It will be evident that the subject comprises two main and consecutive divisions, viz.: first, the formation of the railway as a road or track; and secondly, the furnishing of this road with all the fittings and appurtenances by which it is adapted to the purposes of traffic.

Thus, the one division includes the levelling of the original surface of ground, the raising or lowering it as may be necessary, including tunnelling, the construction of bridges and viaducts to sustain the line over valleys, roads, or rivers, or to carry roads, &c., over the railway; and also the arrangement of rails and their supports,—constituting technically the *permanent way*,—by which the road is specially adapted for the rapid and uniform passage of engines and carriages.

The second division comprehends stations and their fittings, locomotive power and all arrangements belonging thereto, with carriages, &c.

Before commencing the construction, or indeed deciding the course of a railway, there are some preliminary considerations respecting its lateral and vertical deviations from a right line, and also the width of surface that will be

required for the railway, which need the careful attention of the engineer. These deviations constitute the curves and gradients, and the width of surface is determined by the intended gauge of the line and slopes of its cuttings and embankments.

Although involving considerations of a somewhat theoretical character, these subjects claim a portion of our space, in order to exhibit briefly what has been advanced in the way of theory, and what has been adopted by engineers in their practice.

SECTION I.

CURVES, GRADIENTS, GAUGE, AND SLOPES.

The theory of a perfect railway requires that it shall follow a right line on plan, and be uniformly level from end to end.

These two conditions are made impracticable by the interposition of hills, rivers, towns, dépôts, &c., between the intended termini of the line, which must be avoided, or crossed, or passed within certain limits; by the difference of levels of the intended termini; the undulations of the surface of country through which the route will pass, &c.

But all such deviations from the theoretical line are ruled in their nature and extent by circumstances peculiar to the railway system as hitherto carried out by means of steam locomotive power.[1]

Curves.—The principles regulating all lateral deviations are, *first*, that they can be made only in curves, angles being incompatible equally with the speed to be attained on railways, and with the constantly parallel axes of the four or six-wheeled machines impelled upon them; *secondly*, that as the perfect condition is a right line, so does comparative perfection consist in the minimum amount of deviation from it, that is, in the largest possible radius of curvature; and *thirdly*, that in order to impose the least diminution of speed, small curves

[1] It is necessary to remark that the peculiarities of curves, gradients, &c., which distinguish the Dalkey branch of the Dublin and Kingstown Railway, which is now worked upon the atmospheric system, will be disregarded in this series of Papers, which will be devoted to the details connected with the steam locomotive system. The little experience yet had of pneumatic propulsion would exclude it from these Papers, while the great importance deservedly attached to it entitles it to a separate history.

should always be near to stations or stopping-places, and that the more distant curves are from these, the larger should be their radius.

To estimate the effects of curves, let us conceive a railway to consist only of one horizontal rail, traversed by a vertical wheel of infinitely small breadth, impelled by a force exactly sufficient to move it at a given velocity. Even with this arrangement we know that the wheel could not be made to deviate from a rectilineal course, without an additional power, equal to its centrifugal force, be applied to it, or without reducing the velocity of its motion.

If the rail, being curved, present a level surface, and the periphery of the wheel be made of some appreciable breadth, say two inches, it is evident that a rubbing action must take place, tending to wear away the one edge of the wheel and the other edge of the rail, until the former shall assume the figure of the frustum of a right cone having its apex at the intersection of the centre of curvature of the rail with a horizontal line produced from the axis of the wheel; and the rail, in like manner, will become worn to an inclined surface to suit the conical surface given to the periphery of the wheel.

Beyond the power lost in overcoming the centrifugal force of the wheel, there will, therefore, be a further loss incurred by this friction between the wheel and rail.

But if the railway consists of two parallel rails, at some distance, say 5 feet, apart, and is traversed by carriages having two or three pairs of wheels, each pair fixed to one axle, and the two or three axles made, by their connexions with the carriage frame, to revolve always parallel with each other, several such carriages being linked together in one train, and impelled by one engine, it will be seen that not only will this friction be much increased, but that the resistance arising from the centrifugal force will be so likewise.

The wheels on the inner rail will be attempting to describe a smaller curve than the wheels on the outer rail, and will be made to rub backwards upon the rail, while the outer wheels are getting over the excessive space; thus producing a severe torsion of the axles and straining of the frame and the parts connecting it with the axles. The centrifugal force of each pair of wheels may, moreover, be regarded as acting in a direction different from that of each other pair of wheels, and an engine drawing several carriages thus situated will have to overcome the sum of these forces. In reference to this latter effect, it must be also noticed that on entering and leaving the curve, whether in a right line or a curve of contrary flexure, the engine and each of the carriages in succes-

sion will be taking a still more different course than over the curve of equal radius, thus augmenting the effect alluded to.

To mitigate the evils consequent upon the adoption of curves, two expedients have been introduced, viz., giving a conical form to the wheel-tires, and raising the outer rail.

By making the tires of the wheels conical, the bases of the cones being towards each other, it is assumed that when the centrifugal force drives the flange of the outer wheel towards the edge of the rail, and, at the same time, withdraws the flange of the inner wheel from its rail, the diameters of the wheels are rendered practically unequal, in exactly the manner required in order to get rid of the dragging which takes place when equal and cylindrical wheels are made to describe curved lines.

The extent to which this inequality should amount depends, 1st, upon the radius of the curve; 2nd, the sizes of the wheels; 3rd, the distance at which they are placed apart, in other words, upon the *gauge* of the railway; 4th, the velocity at which they are impelled; and 5th, the extent of play allowed between the gauge of the rails and the width across the outside of the wheel-flanges.

Of these five elements there are two, viz., the radius of curvature, and the velocity, which are, of course, various over different parts of the line, and for which, therefore, the same carriages and engines cannot be equally well adapted. One of these, however, may be made somewhat to counteract the other; that is, the velocity may be modified according to the curve traversed, reduced speed producing less centrifugal force, thus forcing the wheels less from their central position, and creating less difference of diameters. It follows, that in order to render the conical wheels available, the speed must be reduced in proportion as the radius of curvature is reduced.

The other expedient, viz., raising the outer rail over curves, was recommended, with other suggestions, by Tredgold, in his 'Practical Treatise on Railroads and Carriages,' first published in 1825.[2] The following is quoted from the second edition of the Treatise, published in 1835.

"When a considerable degree of curvature is given to a railroad, the rails of the outer curve should have a slight rise to the middle of the curve, and the rails should be stronger in a lateral direction in both lines. The object of making a slight ascent to the middle of the curve of the outer rail, is, to

[2] According to Weale's 'Scientific Advertiser,' in the third number of which publication, dated February 20th, 1838, appeared an interesting memoir of this justly celebrated man.

counteract the tendency of the carriage to proceed in a straight direction, without its rubbing so forcibly against the guides, as we have observed in cases where roads have had a considerable curvature. Straight lines ought to be obtained, if possible; but when it is determined to accomplish any object by means of a curved line, the rails should be cast or formed of the proper figure, as no combination of straight rails can be rendered free from angles, which both cause an irregular motion, and a great increase of lateral stress on the rails." (Pages 135-6.)

The object being to counteract the tendency of the flanges of the wheels to rub against the outer rails, (as impelled by the centrifugal force,) it will be seen that this expedient does, to some extent, destroy the purpose sought by making the wheel-tires conical.

Hence it will be readily conceived, that a very delicate and exact adjustment of these contrivances is needed, in order that they shall produce their desired effects.

De Pambour was, it is believed, the first to treat these matters analytically; and as the result of his reasoning, (the general correctness of which is commonly conceded), we may quote his statement,[3] that with an average velocity of 20 miles an hour, a radius of curve of 500 feet, wheels 3 feet diameter, gauge of railway equal to 4·7 feet, and 2 inches play of the wheels between the rails,—the least inclination that should be given to the tires of the wheels is $\frac{1}{12}$th, that is, the tire should belong to a cone, the radius of whose base is to its axis as one is to twelve. He goes on to state,[4] that

" It is customary to give an inclination of $\frac{1}{7}$th. The motive for making it so considerable, is to prevent all possibility of the flange rubbing against the rail, either in case of a strong side-wind, or in case of some fortuitous defect in the level of the rails, by which the waggons would be thrown on the lower rail. Having seen above that, with an inclination of $\frac{1}{12}$th, there would be no danger of the flange rubbing in the curves, that danger will be still more impossible with an inclination of $\frac{1}{7}$th."

Pambour also determines that with this radius of curvature, velocity, inclination of tire, gauge of line, and size of wheels, the outward rail should have a surplus elevation of 2·83 inches.[5]

[3] 'A Practical Treatise on Locomotive Engines upon Railways,' pages 286, &c. (Weale, 1836.) The first edition appeared in French early in the year 1835.

[4] Ibid. page 289.

[5] Ibid. page 287.

Solving his formulæ for some usual cases, he produces[6] the following

Table of the Surplus Elevation to be given to the outward Rail in the Curves.

Designation of the Waggons and the Way.	Radius of the curve in feet.	Surplus of elevation to be given to the rail in inches, the velocity of the motion in miles, per hour, being—		
		10 miles.	20 miles.	30 miles.
	feet.	inches.	inches.	inches.
Waggons with wheel, 3 feet	250	1·14	5·60	12·99
	500	0·57	2·83	6·56
Way, 4·7 feet	1000	0·29	1·43	3·30
Play of the waggon on the way, 1 inch .	2000	0·15	0·71	1·65
	3000	0·10	0·47	1·10
Inclination of the tire of the wheel, $\frac{1}{7}$th .	4000	0·07	0·36	0·83
	5000	0·06	0·28	0·66

Considering, however, the extreme difficulty, if not impossibility, of realizing in practice the exact conditions and proportions determined by these inquiries, it may reasonably be doubted whether by far the larger part of the friction, straining, and loss of power belonging to curves, without these expedients, does not still remain, with their inevitably imperfect execution.

Morever, there is another effect arising from the conical tires, which was thus referred to by the editor of the 'Railway Magazine:'[7]

" It is plain, from the conical structure of the wheels, that if the upper surface of the rail be horizontal, the whole of the pressure must lie on the inner edge of the rails, and be constantly tending to thrust them outwards. This must not only twist the rails out of their vertical position, and thrust them out, but the whole wear and tear being on one edge, and, as it were, on a line, the wheels themselves must wear in grooves, and the rails rub away on the inner edge alone, both of which have already happened on the Liverpool line."

This is usually sought to be corrected, either by inclining the surface of the sleeper or support for the chairs so as to throw the top surface of the rails downwards to suit the wheels, or by forming the chairs so as to hold the rails in this inclined position, or by inclining the top surface of the rail itself.

This method, however well adapted for straight lines, evidently tends, upon curves, to destroy the proper condition of the wheel upon the outer rail, the top

[6] 'A Practical Treatise on Locomotive Engines upon Railways,' page 290.

[7] No. x. December, 1836. Page 405.

surface of which should incline downwards from the other rail, rather than towards it, in such manner that the surfaces of both rails should coincide with a line directed to the point wherein the produced axis of the wheels would meet the centre of curvature of the railway.

In like manner, it will be understood, that the raising of the outer rail is directly destructive of this desirable relation between wheels and rails; and we are thus obliged to recognize some imperfections even in the theory of the expedients referred to, although it may be difficult to conceive how the defects resulting from curves can be practically and completely surmounted.

Without careful experiments (which it is believed have never been made) upon the relative power requisite to move a given load over a straight and a curved line, respectively, both with and without the expedients described, and also with wheels and rails formed to the true conical line, tending to the centre of curve and wheel-axle produced, neither the exact defects of curves, nor the value either of present remedies, or of others that may be proposed, can be satisfactorily ascertained.

As might be predicated from our present state of uncertainty on this subject, we find that the practice of engineers, in the adoption of curves, differs most widely; some securing curves of large radius, at great sacrifices of cost; and others, again, choosing very small ones, on considerations of minor economy.

Thus, on the Great Western Railway, "the curves are in general very slight, chiefly of 4, 5, or 6 miles radius. Mr. Brunel considered, that even a mile radius is not desirable, except at the entrance to a dépôt, where the speed of the engines is always greatly slackened. And, except in these instances, the only deviation from his rule, which he has admitted, is in the curve, about $\frac{1}{4}$th of a mile below one of the inclines, where the radius is $\frac{3}{4}$ths of a mile."[8]

In his evidence on the projected Brighton Railway, in 1836, Mr. R. Stephenson stated, that the line he proposed had no curve of smaller radius than $1\frac{1}{2}$ mile, which he considered a very convenient radius for passenger traffic.

From a quotation which will presently be made, under the head "Gradients," it will be seen, however, that Mr. Stephenson would not limit the minimum of curvatures even to $\frac{3}{4}$ths of a mile, if other circumstances of a sufficiently important character dictate the choice of smaller curves.

On the Birmingham and Gloucester line, (which is curved nearly throughout

[8] 'Railway Magazine,' vol. i. page 418.

its whole length,) on the Edinburgh and Glasgow, and on other railways, the general radius of the curves is 80 chains or 1 mile;[9] while on the Chester and Birkenhead, Birmingham and Derby, Arbroath and Forfar, and others, this is the *minimum* radius adopted for the curves.

The Taff Vale Railway (a single line) was reported in April, 1841,[10] by Sir F. Smith, then Inspector-General of Railways, as having curves of the following radii and length.

	miles.	chains.
10 chains radius	,,	26 in length.
11 ,, ,,	,,	7 ,,
12 ,, ,,	,,	18 ,,
7 ,, ,,	,,	7 ,,
15 ,, ,,	2	41 ,,
20 ,, ,,	2	22 ,,
22 ,, ,,	2	13 ,,
25 ,, ,,	,,	29 ,,
26 ,, ,,	,,	37 ,,
28 ,, ,,	,,	21 ,,
30 ,, ,,	1	8 ,,
40 ,, ,,	1	5 ,,
60 ,, ,,	,,	20 ,,
80 ,, ,,	1	40 ,,

These curves appear to have been adopted to avoid repeated crossings of the river Taff by viaducts, and also to save the formation of some lofty embankments; but Sir F. Smith thought it necessary to propose "that a suggestion should be offered to the Directors of the Taff Vale Railway, recommending them to call upon the engineer to fix the maximum rate of speed to be used round such of the several curves as have a shorter radius than $\frac{1}{2}$ a mile," although it did not appear that any difficulty had been experienced in working the engines round these curves "at a velocity of upwards of 20 miles an hour."

The Manchester and Leeds Railway has curves generally of 60 chains radius, and some which are still less.[11]

The Northern and Eastern Railway joins the Eastern Counties line in a sharp curve, but it is mainly very straight, occasionally extending for several miles in a perfectly straight direction. The gradients are also good.

[9] Whishaw's 'Railways of Great Britain and Ireland.' 4to. 1842. (Weale.)

[10] Report of the Officers of the Railway Department, page 132. 1842.

[11] Whishaw's 'Railways of Great Britain and Ireland.'

The London and Birmingham has been constructed through a difficult country, but with a special view to good curves and gradients. The result is the judicious adoption of moderate curves and gradients.

Each of the lines here referred to has gradients corresponding mainly with the character of its curves, sharp curves and steep gradients being usually allied, and *vice versâ*. Nevertheless, we cannot escape the inference that some, if not much, of the startling difference of the average velocities attained on these five railways,—as exhibited in the following tabular statement, compiled from the 'Third Report of the Officers of the Railway Department,' 1843,—is due to the difference of their curves only.

Northern and Eastern . . .	36 miles per hour.
Great Western	33 ,, ,,
London and Birmingham . .	27 ,, ,,
Manchester and Leeds . . .	24 ,, ,,
Birmingham and Gloucester .	23½ ,, ,,

The last line is distinguished by its very steep gradients and planes, as will be noticed presently.

At or near termini and junctions, which are always arrived at, and departed from, at a very diminished speed, a small radius may be safely used: thus the Chester and Crewe line leaves the latter terminus in a curve of 18 chains radius; and the Grand Junction joins the Liverpool and Manchester in two curves of 10 chains radius each: but throughout the line the greatest possible curvature should be aimed at. Even in approaching first and second-class stations this rule must be kept in view, for the latter ought to be passed by mail and some other trains at full speed, and it may be sometimes essential that the former should also.

Gradients.—The deviations from a horizontal level, constituting the inclinations or gradients of a railway, have to be considered with a careful reference to economy in the construction of the line, involving the quantity of earth-work, of tunnelling, of bridge-work, &c., &c.; and also with a reference to the attainment of the desired velocity from station to station, and to the constant expenses incurred in engine power, and in wear and tear of engines, carriages, and brakes, in working the trains over these inclinations.

Widely differing opinions as to the proper limits of inclination are held and

have been acted upon by the several eminent engineers, under whose management British railways have been constructed. By quoting briefly from these opinions, we shall be possessed of the reasons on which they are built; and an after reference to the practical features of construction and of results obtained upon some existing lines, may assist us to judge of the value of these opinions. The attempt to deduce positive rules from these would be about as difficult as it would be supererogatory, for the actual circumstances of each case present peculiarities which the judgment of the engineer must estimate, and his discretion can alone provide for.

In a Paper on the '*Economy of Railways in respect of Gradients*,' by Mr. Vignoles, read at the tenth meeting of the British Association for the Advancement of Science, held in September, 1840, the author "disclaimed asserting that sharp curves or steep gradients were preferable to straight and level lines; but he would endeavour to show that good practicable lines might be and had been constructed, on which trains sufficient for the traffic and public accommodation could and did move at the same, or nearly the same velocities, and with little, if any, additional expense. On an average, the hitherto ascertained cost of the principal lines might be divided thus:

Land	10	per cent.
Stations and carrying establishment	20	,,
Management	10	,,
Iron	10	,,
Works of construction proper	50	,,
	100	

though of course these items differed considerably in various railways; but in general it might be said that the works of construction constituted one-half of the whole first cost." Mr. Vignoles stated "that he had analysed railway expenses of working, and had reduced them to a mileage,—that is, the average expense per mile per train, as deduced from several years' experience and observations of various railways under different circumstances, and with greatly different gradients, some of which lines were enumerated. The result on passenger and light traffic lines was, that the total deductions for expenditure from gross receipts was 3*s.* per mile per train; 2*s.* 6*d.* being the least, and 3*s.* 4*d.* the highest; and that this average seemed to hold good, *irrespective of gradients or curves*."

This extraordinary inference, coming with weight from the engineer here quoted, might yet have acquired additional interest, had the data been exhibited along with it. That the lower rates of expenditure accompanied the slight gradients, and the higher the steep ones, could be understood more readily and accredited upon less evidence than the proposition above quoted. The Report of the Paper proceeds thus:

"Particular lines might, from local circumstances, differ in detail; but he was satisfied that the following detail was a fair average approximation:

	s.	d.
Daily cost of locomotive power and repairs	1	6
Annual depreciation, sinking fund, and interest on stock, tools, shops, and establishment	0	6
Daily and annual cost in carriage department	0	4
Government duty, office expenses, police, clerks, guards, management, and maintenance of railway	0	8
	3	0

"It was not found practicable to distinguish the additional expense, if any, arising from curves or gradients; but as three-fourths of railway expenses were quite independent of these curves, such addition must be small; especially as in the North Union Railway, a line which had 5 miles out of 22 in the gradients of 1 in 100, or nearly 53 feet per mile, the total expenses were less than on the Grand Junction Railway, and several other lines." [12]

This statement seems sufficiently important to warrant the quotation in this place of some of the details connected with the line referred to, the North Union, which connects Preston with the Liverpool and Manchester Railway at Parkside.

The gradients, as given in Mr. Whishaw's work, already quoted, are as follow:

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[12] 'Civil Engineer and Architect's Journal, vol. iii. p. 422.

Length of planes. Yards.	Ratio of Inclination.	
203½	descending at the rate of	1 in 100.
1368	descending ,,	1 in 330.
1518	ascending ,,	1 in 330.
1100	ascending ,,	1 in 100.
3520	ascending ,,	1 in 330.
760	ascending ,,	1 in 100.
1660	ascending ,,	1 in 440.
2750	descending ,,	1 in 660.
1584	ascending ,,	1 in 100.
350	ascending ,,	1 in 330.
946	ascending ,,	1 in 100.
1210	ascending ,,	1 in 330.
616	ascending ,,	1 in 100.
958	ascending ,,	1 in 528.
770	descending ,,	1 in 100.
3740	descending ,,	1 in 330.
1298	descending ,,	1 in 100.
462	descending ,,	1 in 330.
1100	descending ,,	1 in 100.
814	descending ,,	1 in 330.
209	level.	
253	descending ,,	1 in 100.
990	descending ,,	1 in 330.
1326	descending ,,	1 in 754.
660	level.	
1320	ascending ,,	1 in 2200.
1754	ascending ,,	1 in 586.
1232	ascending ,,	1 in 440.
4664	descending ,,	1 in 406.

39,135 yards, or 22·236 miles.

"The ascending planes rising 1 in 100 from Preston to Wigan amount to 5006 yards, and in the opposite direction to 3624½ yards, or together 4·90 miles, being equal to more than one-fifth of the whole length.

"This is an important fact, as showing the inutility of spending large sums of money in reducing hills and filling up valleys to so great an extent as has been done on many of the great lines of the kingdom, for the purpose of making the gradients as easy as possible."[13]

[13] Whishaw's 'Railways of Great Britain and Ireland,' 4to. 1842. Weale.

The average cost per mile of this railway was £23,157. 5*s.* 6*d.*; the receipts for the first half of the year 1840, £32,394. 3*s.* 11*d.* (including £467. 16*s.* 5*d.* derived from the carriage of coals, and £500 rental); and the disbursements for the same period were £16,396. 3*s.* 4*d.*, about 50 per cent. of the receipts. The cost of the locomotive department was at the rate of £7546. 3*s.* 6*d.* per annum; and of maintenance of way £1200 per annum, or about £50 per mile.

Interesting as these figures are, however, as relating to an individual railway, and satisfactory as showing a cheap construction through a rugged country and bad strata, and showing also a moderate rate of expenditure, both for engine-power and road repairs, it must be observed that they do not warrant the general inference that steep gradients may be adopted with equal advantage to easy ones; neither do they afford the materials for an advantageous comparison with other lines which have cost more money both in original construction and in current expenditure.

Thus, in a comparison on this subject made by Mr. Brunel, in reference to the system of easy gradients adopted by him on the Great Western Railway, the data are explained on which is founded the following "Table of the comparative effects of the same engine, with the same consumption of fuel, and travelling at the same speed on the level, and on the four gradients of 4, 10, 16, and 20 feet per mile.

	Comparative effective power. Ascending.	Descending.
Level	170	170
4 feet per mile	134	226
10 feet per mile	100	400
16 feet per mile	77	1305
20 feet per mile	66	The load once in motion would *run* of itself.

"Hence," Mr. Brunel proceeds, "the great superiority of a line approaching to the level is made apparent; not only is the effective power of the engine in that direction of the line which limits the load much greater, but the average work of the engine is performed more economically by the greater regularity of the resistance. On an inclination of 10 feet per mile, as I have before shown, the engine, during half the time, is barely performing a quarter of the

work of which it is capable. On gradients of 16 feet per mile, the engine during half the time is barely doing more than driving itself." [14]

The economy in construction attained by the adoption of steep gradients will consist, according to the features of the country passed through, of many items; thus, the cuttings being less deep and the embankments less high, a much smaller quantity of land will be required, and the ratio of saving in this respect increases rapidly upon the proportion of height or depth avoided. A very large saving also occurs in the size and cost of bridges and cuttings, and bridges or viaducts under the embankments; and in these, also, the saving increases in a greater proportion than the difference of length or height effected; the foundations, abutments, and general dimensions being necessarily much increased in the larger structures. The passage over rivers and through towns is also, in many cases, much facilitated by keeping more closely to the original surface of the country. The smaller cuttings and embankments, moreover, require less expense in drains and culverts, &c.; and to crown the economy of the steep-gradient system, it must be remembered that those costly nuisances, tunnels, may in many cases under its adoption be either wholly avoided, or very much reduced in length; and it may, further, escape interference with some of those treacherous strata, which so much impede the progress and augment the cost of works of that kind.

The question arises, how far are these sources of economy in first cost counterbalanced by increased expense in locomotive power, or stationary engines, traction ropes, &c., or the repair of the permanent way,—and further, to what extent is the great purpose of railway travelling,—economy of time,—sacrificed by the adoption of the less level line? The latter part of this question, relating to the time occupied in the transit, seems to have been determined (as far as they extended) by some experiments made upon the Grand Junction Railway, between Liverpool and Birmingham, in the year 1839, and reported by Dr. Lardner to the meeting of the British Association for the Advancement of Science, held in that year. The hypothesis, which these experiments were designed to test, and found to confirm, is, that "a compensating effect is produced in descending and ascending the gradients, and that a variation of speed in the train is the whole amount of inconvenience that will ensue; that the time of performing the journey will be the same in

[14] Mr. Brunel's Report to the Directors of the Great Western Railway Company, dated Dec. 13, 1838, and published in the 'Civil Engineer and Architect's Journal,' vol. ii. page 55.

both cases."[15] The result of these experiments is exhibited in the following Table, quoted chiefly from the same journal.

Gradient.	Speed.		Mean.
	Ascending.	Descending.	
One in	Miles per hour.	Miles per hour.	Miles per hour.
177	22·25	41·32	31·78
265	24·87	39·13	32·00
330	25·26	37·07	31·16
400	26·87	36·75	31·81
532	27·35	34·30	30·82
590	27·27	33·16	30·21
650	29·03	32·58	30·80
Average mean speed of the seven gradients . .			31·23
Level			30·93
Loss of speed on the seven gradients			·30

These experiments do not, however, afford any evidence upon the former part of the question before stated, regarding the *cost* of power and road repairs. On one of these points we may refer to a note appended to the Report of the Irish Railway Commissioners, made in the year 1838, and which also contradicts, essentially, the results stated in the preceding document as to *time*.

" It is agreed on all sides, that the additional force requisite to urge a load up an inclined plane or gradient, is such a fraction of the gross load (that is, with engine and tender included,) as expresses the slope of the plane, or the fraction of the height of the plane divided by its length.

" The disputed point is,—what is gained by the returning load descending the same plane? It has been maintained, that the power which is lost in causing a load to ascend a plane is gained by an equal returning load descending the plane; a deduction, however, which has been controverted by others. Without stopping here to discuss this question, the Commissioners will state the facts they have been able to collect on the subject, and which have been obtained by proposing the following queries to the engineers of the several present existing lines:

" First.—When a plane inclines so much as to give to the engine and load a

[15] Report in 'Civil Engineer and Architect's Journal,' Oct. 1839, page 387; extracted from the able Report published in the 'Athenæum.'

tendency to acceleration, what is the greatest velocity it is deemed prudent to descend with, in comparison with the usual horizontal velocity; or, to specify more particularly, what velocity would it be deemed prudent to descend with on slopes of $\frac{1}{90}$, $\frac{1}{100}$, $\frac{1}{110}$, $\frac{1}{120}$, &c., supposing the horizontal velocity to be 25 miles per hour?

"Second.—What is the greatest slope on which it is deemed prudent to allow of acceleration, and to what amount?

"Third,—On medium slopes, what may be considered the excess of allowable descending velocities beyond the mean horizontal velocity?

"The answers to these queries were not entirely accordant; but it would appear that no advantage can be claimed for descending planes of greater slope than $\frac{1}{140}$, and that the greatest allowable increase in the descending velocity on planes between $\frac{1}{140}$ and $\frac{1}{750}$ is one-fifth of the uniform horizontal velocity: on less slopes than $\frac{1}{750}$ the gain from descent varies from one-fifth to nothing.

"It appears, therefore, that whatever advantage may show itself theoretically on descending planes, there is no practical advantage for those of greater slope than $\frac{1}{140}$; and allowing an advantage of one-fifth additional velocity for planes of less slope than $\frac{1}{140}$, and greater than $\frac{1}{750}$, we are in general on the most favourable side.

"It may be said that these descending velocities are obtained with less piston pressure, which is true; but the steam thus saved in the cylinders is commonly lost at the safety-valve, so that there is little, if any, saving of steam beyond what has been stated.

"One or two cases may now be taken by way of illustration.

"Let us suppose a load of 88 tons (tender included) to be drawn along a level plane at the rate of 20 miles per hour, and that this engine and train arrive at a rising plane, sloping 1 in 140; the engine being of the first class, viz., weight 12 tons, and tender 6 tons:—

The power absorbed is	1075 lbs.
88 tons, at 9 lbs. per ton . . .	792 ,,
	1867 ,,

which is the pressure required on the horizontal plane."

This calculation is the same as that adopted by De Pambour, in his 'Treatise on Locomotive Engines,'[16] and assumes the retarding forces which have to be

[16] Weale, 1836.

overcome by the power created within the locomotive engine, before any of that power is available for moving the train, as four in number; viz.—1, the friction of the engine gear independently of any load, equivalent to 6 ℔s. per ton of the weight of the engine;—2, the friction of the locomotive itself, the friction of the axles, and retardation on the line of way, equivalent to 8 ℔s. per ton;—3, the friction of the tender itself, including the increase of friction brought on the engine gear, equal to 9 ℔s. per ton of the weight of the tender;—and 4, the atmospheric pressure on the piston, which is necessarily 14·7 ℔s. per square inch. This force being employed at the extremity of the piston rod, and overcome only with the velocity of the piston, must be reduced according to the relative ratio of the velocities of the wheel and piston.—(Report of the Irish Railway Commissioners.)

Thus estimated, the power absorbed in the overcoming of these four retarding forces, in the four classes of engines adopted (after six years' experience) by the Directors of the Liverpool and Manchester and other Railway Companies, was equal respectively to 1075 ℔s., 786 ℔s., 702 ℔s., and 640 ℔s. The whole power of these several engines being found by multiplying the area of their respective pistons by the steam pressure, viz., 64·7 ℔s., (50 ℔s. per square inch added to 14·7 ℔s. pressure of the atmosphere,) and reducing this product to the circumference of the wheels in each class of engine, it appears that the

	Class 1.	Class 2.	Class 3.	Class 4.
Whole power is . .	3755	2488	2337	2090
Absorbed power . .	1075	786	702	640

The mean force necessary to overcome the friction of the best constructed carriages and waggons on a level line amounts to 8 ℔s. per ton of the gross load, and 1 ℔. per ton additional of the said gross load for the extra friction brought on the engine gear; in all 9 ℔s. per ton.[17]

[17] We must here quote the following correction of this datum, from the Report of I. K. Brunel, Esq., to the Directors of the Great Western Railway Company, dated December 13th, 1838. (Given in the C. E. and A. Journal, vol. ii. page 54.

"I have assumed 8 ℔s. per ton as the resistance of a train; but as the greatest part of this resistance depends upon the workmanship, the form, and the mechanical construction of the carriages, and other causes, and may be reduced by various contrivances already known, it would be contrary to all experience to suppose that it will not be materially reduced when there is an object to be gained by its reduction.

"In many experiments, with all the circumstances favourable, the resistance has been as low as 6 ℔s.

The note appended to the Commissioners' Report proceeds thus:

"To this is to be added the additional traction necessary to cause the loads to ascend the plane: we must now, therefore, add the weight of the engine itself, 12 tons; making the whole load to be raised 100 tons, or 224,000 lbs., and $\frac{1}{140}$th part of this is 1600 lbs. additional traction. But it has been seen that every 8 lb. traction causes 1 lb. additional friction on the engine gear; this makes 1800 lbs.: the whole required force now, therefore, is 3667 lbs.; and the velocity being inversely as the pressure, or force of traction, we have

$$3667 : 1867 :: 20 : 10\tfrac{1}{6}$$

miles per hour, the velocity of ascent: that is, the time of ascending will be nearly double that required to go the same distance on a horizontal plane, but in the return the time of descent will be the same as on a horizontal plane; so that ascending and descending a plane of this slope with a load of 88 tons, will require the same time and power as would be necessary to pass and repass a horizontal plane of one-half greater length; or, calling the length of the gradient 1, the equivalent horizontal plane will be 1·5.

"Taking now the same engine and load, and the slope of the plane $\frac{1}{500}$, let it be required to find the equivalent horizontal plane.

Here the absorbed power, as before, is . .	1075
88 tons, at 9 lbs.	792
Traction on a level . .	1867

$88 + 12 = 100$ tons $= 224,000$ lbs.: this divided by 500 gives 448 lbs., which is equivalent to the traction of 56 tons on a level; and this at 9 lbs. per ton is 504 lbs. additional pressure. The whole pressure is, therefore, 2371 lbs., and

$$2371 : 1867 :: 20 : 15\tfrac{3}{4}$$

miles, nearly, and

$$1867 : 2371 :: 1 : 1{\cdot}26$$

length of horizontal plane equivalent to the ascending plane. And, again,

$$1\tfrac{1}{5} : 1 :: 1 : {\cdot}83$$

"In some made by Mr. Hawkshaw, on the Great Western Railway, the resistance of a train, consisting partly of trucks, and partly of carriages, only gives 6·22 lbs.

"It may therefore be assumed, that we have now within our reach improvements by which the resistance may be reduced to 6 lbs."

length of horizontal plane equivalent to the descending plane. Whence 1·20 + ·83 = 203 ÷ 2 = 1·015 mean equivalent plane."

The Commissioners furnish eight Tables computed from the data here quoted, and showing the horizontal lines equivalent respectively to each of a series of 18 gradients, varying from 1 in 90 to 1 in 1500; with each of the four classes of engines, and loads from 30 to 100 tons.

"It is to be observed, however, that the effect thus shown (by the Tables) is not all the effect that is due to the gradients and planes; for it is these planes which limit the amount of load. If a line is wholly horizontal, and the traffic abundant, the loads may be chosen so as to bring out the best effect; and it has been seen, that the greater the load within the power of the engine, the greater the economy of working; but when it is required to ascend planes without assistant power, the load must be taken such that it will ascend the plane with a certain velocity.

"The engines are thus obliged to work with small loads, and all the loss attending such loads must be considered to increase to the above disadvantages.

"Thus, for example, in ascending a plane of 1 in 140, with a load of 100 tons, it appears by Table V. that the force of traction would be doubled, or be equivalent to the traction of 200 tons on a level. In order, therefore, that the engine may ascend this plane without assisting power, it would be deemed necessary to reduce the load, probably to 60 tons: and then again, by referring to Table I., it appears that all the expenses of haulage are increased 36 per cent.; not only, therefore, is the equivalent horizontal plane about one-half longer than the real length of the actual plane,[18] but the expense of working the whole distance is increased 36 per cent."

A practical answer to this position was thus put forward by Mr. Vignoles, in the Paper read before the British Association in the session of 1840, and already quoted:

"It was forced on him by daily experience, that to accommodate the public convenience, the Post-Office arrangements, and business in general, it was scarcely once in twenty times that a locomotive engine went out with more than half its load, and in general the engines were only worked up to two-fifths of their full power: he was therefore conclusively of opinion, that it was much cheaper to put on additional engines on extraordinary occasions; and on such

[8] That is, the *horizontal* distance passed over.

principle, railways should be constructed through the more remote parts of the country, so as to be made in the cheapest possible manner."

The Commissioners proceed:

"This points out the advantage of accumulating the ascents as much as possible into short steep planes, and working these planes by assistant engines, either motive or stationary: for although there is really no saving of power by this arrangement, there is a saving of time; and what is of more importance, it will not be necessary to reduce the amount of the loads below what would be otherwise considered as most advantageous for the general traffic."

Mr. Robert Stephenson, whose opinions are understood to be decidedly in favour of easy gradients, in reporting to the Chairman and Directors of the South Eastern Railway Company upon the proposed railway communication with France and Belgium, declares,—

"Though I appreciate more highly than the generality of the profession the ultimate benefits which I believe will always be found to spring from the use of favourable gradients, yet I cannot but feel, and that very strongly, that the application of precisely the same principles as those which governed me in designing the London and Birmingham Railway to the section of country now under my consideration, between Paris, Belgium, and the northern coast, must lead to consequences which the Government and every interested individual would hereafter have reason to lament."[19] The remarks from which this is quoted were made in reference to the following restrictions, imposed by the French Government upon M. Vallée, in deputing him, in 1835, to report upon the opening of a railway communication between Paris and the northern parts of the country, as well as with the kingdom of Belgium and with England.

"1. That no curve should be made under 1200 metres (three-quarters of a mile) in radius.

"2. That no gradient should exceed 3 in 1000, or, as it is expressed by English engineers, 1 in 333, or about 16 feet a mile; and

"3. That all curves of small radii should be level."

Some further materials for determining the value and cost of easy gradients will be offered in a subsequent part of this work, when treating of earth-works, tunnelling, viaducts, locomotives, &c. Meanwhile we conclude the subject at present by quoting from the useful volume of Mr. Whishaw the peculiarities of gradients upon several of our English railways.

[19] 'Railway Times,' Nov. 12th, 1842.

Birmingham and Derby.—The terminal planes are both level, and the greatest inclination throughout the line is 1 in 339.

Birmingham and Gloucester.—The inclinations vary from 1 in 100 to 1 in 1000, excepting the Lickey incline, which ascends at 1 in 37 for a length of 2 miles 3·35 chains from the Bromsgrove Station, and excepting also a length of 1 mile 09·09 chains which descends at 1 in 84 towards a level plane of 19 chains, which joins the line to the London and Birmingham Railway. The Lickey incline is worked by assistant locomotive engines of the American kind, of which some account will be found under the heads "Inclines," and "Locomotive Engines." The summit of this railway, near the Lickey, is 400·73 feet above the level of the rails at Cheltenham, and the junction with the London and Birmingham line is 191·35 feet above the same level. The longest plane of 1 in 100 is 32·30 chains in length, and all the planes inclined at this rate are between others of less steepness. The prevailing gradient is 1 in 300, and the longest plane is 4 miles 20·05 chains in length, inclined at 1 in 300.

Eastern Counties.—This line has one plane of 2 miles 75 chains in length, ascending at 1 in 100 to the station at Brentwood.

Edinburgh and Glasgow.—The gradients vary from 1 in 880 to 1 in 5456, except one incline of 1 mile 14 chains in length, which descends from the Cowlairs towards the Glasgow Station at the rate of 1 in 43, and has been hitherto worked by stationary steam engines which are now, or are about to be, replaced by American locomotive engines. On this line there is one plane at 1 in 880, 6 miles long; another of the same length at 1 in 1056; another of 5 miles of the same inclination; one level plane 6 miles 69·72 chains in length, and one of 10 miles 59 chains in length, and inclined at 1 in 1158·66. These gradients have, however, been secured by extensive earth-works and about $1\frac{1}{3}$ mile of tunnelling. The Abercorn cutting is 50 feet deep and nearly 3 miles long.

Grand Junction has gradients varying from 1 in 85 to 1 in 3474, and one incline (at Madeley) which extends for $3\frac{1}{4}$ miles at 1 in 177; another at Newton Brook, 1 mile in length, and inclined at 1 in 85. The entire line from Birmingham to Newton is 82·63 miles, of which 10 miles 47·44 chains are level.

Great Western, 117 miles in length, has 35 miles graduated at 4 feet per mile, or 1 in 1320;—$13\frac{1}{2}$ miles at 7 feet per mile, or 1 in 754·28;— $19\frac{1}{2}$ miles at 8 feet per mile, or 1 in 660, and 10 miles level. It has also two planes, viz.:

at Wootton Basset and Box, inclined at 1 in 100, the former being 1 mile 29 chains long, the latter 2 miles 30 chains in length. The fall from London to Bristol is 27·33 feet.

Leeds and Selby.—This line has some rather severe gradients: there are two contiguous planes ascending in the same direction, one of which is 2 miles 4·80 chains in length, at 1 in 160; the other, 1 mile 4·20 chains long, inclined at 1 in 168: these are succeeded by a level plane, 2 miles 61 chains in length, which is followed by two descending planes, one 2 miles 47 chains long, inclined at 1 in 150; the other, 3 miles 21 chains long, at 1 in 137. The whole line is 20 miles in length. At Leeds the rails are 100 feet higher than at Selby.

Leicester and Swannington has two inclines, 1 in 29, and 1 in 17, both worked by stationary steam engines.

Liverpool and Manchester, 30·66 miles in length, has one plane of 1 mile 30 chains, inclined at 1 in 88, and worked by stationary steam engines at Edgehill. The Whiston incline is at 1 in 96 for a length of 1 mile 47 chains. The Sutton incline is 1 mile 39 chains long, at 1 in 89. This line has one plane of $6\frac{3}{4}$ miles in length, inclined at 1 in 894.

London and Birmingham descends from the terminus at Euston Square for 12 chains, at 1 in 156, is then level for 13 chains, and the succeeding 59 chains are divided into four gradients ascending to Camden Town at 1 in 66, 1 in 110, 1 in 132, and 1 in 75, respectively. Four summits occur between London and Birmingham, viz., at Tring, Blisworth, Kilsby, and Berkswell, which are 332 feet 4 inches,—170 feet 10 inches,—308 feet,—and 290 feet, respectively, above the level of the Euston Station. One plane occurs which is 7 miles 18 chains in length, at 1 in 330;—29 miles 57 chains of the entire line are graduated at this inclination; and, with the exception of the 1 mile and 4 chains between the Euston Terminus and the Camden Dépôt, already mentioned, and constituting the fixed-engine planes, the most severe gradient throughout the line is 1 in 326.

London and Brighton, which is $42\frac{1}{2}$ miles in length, has $32\frac{3}{4}$ miles graduated at 20 feet per mile, or 1 in 264. This line has one plane of 8 miles 42 chains, ascending at 1 in 264 from London to the Merstham summit; then occurs a level plane of $\frac{3}{4}$ mile, succeeded by a descending plane of 6 miles 69 chains, at 1 in 264. It has four other planes of about 4 miles long each, at 1 in 264 and 1 in 391, and enters Brighton in a descending plane of 5 miles 33 chains in length, at 1 in 264. Notwithstanding these long gradients, the earth-works

are of a very heavy character, being at the rate of nearly 160,000 cubic yards per mile, besides the contents of the tunnels, the principal of which are at Merstham, Balcombe, and Clayton Hill.

London and Croydon descends to the New Cross Station in a plane of nearly $2\frac{3}{4}$ miles in length, at 1 in 100; and such trains as have to ascend this plane immediately after stopping at the New Cross Station, have the assistance of another engine up a part of this incline.

London and South Western has a plane of $16\frac{1}{2}$ miles in length, inclined at 1 in 250, with a short level plane introduced near the middle of it. The total length of the level planes is 17 miles 22 chains; and of the planes graduated at 1 in 250, 20 miles 2 chains. The total length of the railway is 76 miles 55 chains. The difference of level between the termini is 1 foot 8 inches, but the summit of the line, distant 54 miles from London, is 392 feet above the London, and 390 feet 4 inches above the Southampton terminus.

Newcastle and Carlisle has three adjoining planes inclining in the same direction, at the rates respectively of

1 in 176	3	miles	35	chains long,
1 in 106	3	,,	70	,,
and 1 in 215	3	,,	65	,,

making in a length of 11 miles 10 chains, a total difference of elevation of 390 feet.

South Eastern has a prevailing gradient of 20 feet per mile, or 1 in 264.

Whatever ratio of inclination may be adopted for the gradients, there are two maxims which should always be adhered to, and will be found productive of economy, safety, and convenience in the working of the railway. These are, first:—Let the gradients contiguous to stations always rise towards them in each direction, so that every station shall occupy the summit of the adjoining gradients. To effect this, if the section is nearly level, will be an easy matter; but in cases where it is desired to place a station within the length of a steep gradient, it will be desirable to interrupt the inclination at this point by a short plane inclining in the other direction. Where the point destined for a station occurs at the common base of two gradients of opposite inclination, the same object should be attained by dipping each gradient somewhat lower than otherwise necessary, so as to secure a comparative eminence for the station. The value of this arrangement is twofold, consisting in the assistance it affords to engines at starting, and in the salutary check thus presented to the

speed of engines and trains arriving at the station. These advantages, and the circumstances under which they are needed, are thus mentioned by De Pambour.[20]

"There is also another circumstance in which the engines are obliged to exert an additional effort. That is at the moment of starting. We have seen, in fact, that the power which, when the motion is once created, need only to be constantly equal to the resistance, must, on the contrary, surpass it at the instant that it is to put the mass in motion. The reason is plain: in the first case, it is only necessary to maintain the speed; in the other, it must be created and maintained. It is this additional effort on the part of the moving power which is improperly called *vis inertiæ*, because it is attributed to a particular resistance residing in the mass.

"The starting is, therefore, a difficult task for a locomotive engine heavily loaded. However, at that moment the engine acquires, as well as on the inclined planes, a considerable increase of power. Here again the slowness of the motion produces two effects. The pressure in the cylinder grows equal to the pressure in the boiler, which is itself augmented by the effect of the spring balance. But, notwithstanding this twofold advantage, the difficulty of starting still remains so great for considerable loads, that we should always advise giving in that point a slight declivity to the way. By that means the trains would be set in motion with more ease at the departure, and it would not be necessary at their arrival to make use, in order to stop them, of the powerful brakes, the effect of which is certainly as destructive to the wheels of the waggons as to the rails." (p. 296-7.)

The other maxim concerns long inclinations of considerable steepness, which should always be divided into two or more lengths by introducing short planes, either level, or, still better, inclining slightly in the opposite direction. These brakes or benches become as resting-places to the loaded engine, giving the engine-driver an opportunity of easing the steam pressure in ascending, and serving to moderate the speed in descent.

As connected intimately with the subject of gradients, the consideration of the effect in resisting the motion of railway trains which is due to the displacement of the surrounding air, occurs to us here, and will be duly rendered by quoting from the second Report of the Committee on Railway Constants, made

[20] 'Practical Treatise on Locomotive Engines.' 1836. (Weale.)

by Mr. Edward Wood, to the eleventh meeting of the British Association for the Advancement of Science.[21]

"In a preceding Report of the Committee, five various modes of ascertaining the resistance to the tractive power on railways were described, and their relative merits discussed; and a variety of experiments on one of these methods, viz., by observing the motion of a load down an incline, sufficiently steep to give accelerated motion, having been made, it appeared, that the resistance increased in a degree previously unsuspected in proportion as the speed of the train increased; but in what ratio, was not then determined, owing to certain discrepancies, due principally to the varying effect of the wind at the time of the experiments. The Committee have continued to conduct their experiments in a similar manner, repeating them with various sizes of trains, at various velocities, on the Sutton incline, of 1 in 89, on the Liverpool and Manchester Railway, and on the inclines of 1 in 177,—1 in 265,—and 1 in 330, on the Grand Junction Railway."—"Three first-class carriages were allowed to descend the Sutton incline from rest four times in succession, a length of 2420 yards. It appears that the resistance diminishes until the train attains the speed of 7·58 miles per hour, after which it increases; at 4·32 miles per hour, the resistance was 6·07 lbs. per ton; at 7·58 miles per hour, 5·6 lbs. per ton. This remarkable and hitherto unobserved result is owing, probably, to the more perfect lubrication of the axles at the higher speed; a certain thickness or film of grease is formed between the brass step and the upper surface of the journal, and keeps the two surfaces more effectually apart: at the lower velocities, the pressure of the step upon the journal has a longer time to act in effecting the displacement of the fresh grease which has been supplied from the box, and the result is a greater amount of friction.[22] Eight second-class carriages were allowed to descend the Sutton incline; the friction was a minimum at 5·84 miles per hour. The following results may be deduced from the above-mentioned series of experiments:

"1. The friction was least when the train was moving at the rate of about 6 miles per hour.

"2. The total resistance was also least at the rate of about 6 miles per hour, notwithstanding the effect of the atmosphere at that speed.

[21] Given in the 'Athenæum,' and extracted therefrom into the 'Civil Engineer and Architect's Journal,' vol. iv. p. 323.

[22] This hypothesis accounts only for one of the results observed, viz., the diminution of resistance

"3. The mean resistance of first-class carriages was never less than 5·6 lbs. per ton, and of the second class never less than 7·75 lbs. per ton: 6 and 8 lbs. per ton will represent very nearly the mean of the resistances; and these values are used in the subsequent part of the Report. The motion of these trains being observed at lower parts of the incline, where the velocities were greater than the preceding, the resistance to the train of three carriages was 8, 12, and 16 lbs. per ton, at velocities of 22, 26, and 29 miles per hour, respectively; and the resistance to the train of eight carriages was 11, 12, and 14½ lbs. per ton, at the velocities of 20, 25, and 29 miles per hour. Trains of four and of six carriages were impelled to the summit of the incline, and, the engine being detached, commenced their descent at the rate of 33 and 26 miles per hour. They descended through the first half of the incline with a mean velocity of 34 and 29 miles per hour, and through the latter half, with a mean velocity of 37 and 33 miles per hour. Other series of experiments were made on the Grand Junction inclines; and the result of the whole shows the existence of an opposing power, created as it were by the speed itself, far exceeding that hitherto suspected.

"A train of eight carriages, weighing 40½ tons, was started down the Madeley incline, 1 in 177, at speeds varying from 23 to 26 miles per hour: the mean speed attained was 25½ miles per hour. The motion of the train became uniform, so that the co-efficients of gravity and resistance were equal. The mean resistance of the train was 12½ lbs. per ton. A train of four carriages was started down the incline at 40 miles per hour; half-way down the plane the velocity was reduced to 30 miles per hour, and at the foot, it was only 25 miles per hour. Four other carriages were started at a velocity of 32·7 miles per hour; they were retarded to 22·7 miles per hour, and proceeded with this uniform velocity to the foot of the incline. The results obtained in these experiments with the trains of eight carriages are of great practical importance, this being the nearest approach to the average passenger trains. 30 miles per hour is a fair average speed, and the resistance at this speed is about 15 lbs. per ton, or almost double the value of the friction only. The friction may be diminished by proper attention to the fittings, and the perfect lubrication of the axles, but its reduction is of secondary importance in the economic working of

accompanying the increase of velocity up to 7·58 miles per hour: the subsequent increase of resistance is attributed to the displacement of the air, as explained in the body of the Report here quoted.

passenger trains, which, from their high velocity, must necessarily bring into play large and independent sources of resistance.

"The resistance to trains at different speeds being ascertained, the Committee directed their attention to the effect of external configuration on the resistance;" and from their experiments "concluded that the form of the front has no observable effect, and that whether the engine and tender be in front, or two carriages of equal weight, the resistance will be the same. The intermediate spaces between the carriages were closed in by stretching strong canvass from carriage to carriage, thus converting the whole train into one unbroken mass. The results were in favour of the train without canvass, but the differences are extremely slight: it is certain that no additional resistance is occasioned by leaving open spaces between the carriages, confining the intervals to the dimensions allowed in practice."

It must be observed here that no record appears as to the *speed* at which these experiments upon "the effect of external configuration" were tried. Upon the speed would, I apprehend, depend much of the result. The surrounding air may be in a state of comparative quiescence, or it may be moving at a slow rate in the same direction as the moving train, or in a direction opposite to, or different from, that of the train. Under either of these circumstances the rapid passage of a train at a high velocity would cleave its way through the air, and, by its very quickness, (many times greater than that of the motion of the air,) clear the way for all that followed it, giving no time to the adjacent air to penetrate between the carriages, or create any resistance after that encountered by the leading carriage or engine; whereas at a less velocity, below 7·58 miles per hour, the surrounding air has an opportunity of playing with a retarding effect between the several carriages in the train, and thus practically creating a great resistance, which of course diminishes with the augmentation of the velocity up to that speed (probably 7 or 8 miles per hour) at which the train "outstrips the wind." Deeming this suggestion entirely accordant with common sense, and consistent with the reporters' own experiments, I would beg to advance it not in preference to, but to be considered along with, the explanation they offer of the fact of resistance diminishing with the increase of speed up to 7·58 miles per hour, and referred to in Note 22.

"The Committee having ascertained that the excess of resistance, after deducting friction, required for its estimation something besides the elements of the dimensions and forms of frontage, and of continuity of surface, it becomes

important to inquire what is the element exerting so powerful an influence? Their former Report contains the results of experiments with waggons on the Madeley incline, loaded to 6 tons each, and furnished with boarded fronts and sides, moveable at pleasure: the differences in the results attained were then referred to the increased frontage alone. But the experiments detailed in the present Report having been made, it became probable that the increased resistance was in a great measure dependent on the general volume of air displaced; and the Committee recommend experiments to be directed, to ascertain the effect on the resistance of diminishing and increasing the bulk of trains, the weight remaining the same."

It is very desirable that the course of experiments here recommended by the Committee should be prosecuted; more especially as those here recorded as having been already instituted, appear to warrant a somewhat different inference from that drawn by the reporters. Their assertion of the probability "that the increased resistance was in a great measure dependent on the *general volume* of air displaced," seems entirely inconsistent with the results of the experiments previously reported upon one train of eight carriages, and two others of four carriages each. From these it appeared that the eight carriages, which must have displaced twice the *general volume* of air displaced by the trains of four carriages each, yet suffered a resistance which only reduced their velocity from 26 to 25½ miles per hour; while the four-carriage trains met with resistances that reduced their velocity in one case from 40 to 25 miles per hour; in the other, from 32·7 to 22·7 miles per hour. It might have been inferred, that at any velocity above that which would allow the surrounding air to enter between the several carriages of the train, the resistance was proportioned to the *velocity* only, being unaffected by the volume of air displaced, (provided the front surface of the leading carriage or engine remains the same,) but of course liable to be overcome by the superior gravity of the mass descending the plane, as shown by the slightly abated velocity of the heavy train of eight carriages.

Gauge.—On this subject it is necessary only to quote some passages from the Reports made by Mr. I. K. Brunel and Mr. N. Wood, to the Directors of the Great Western Railway Company, in which Reports all the reasons that can be urged as affecting this detail of railway engineering are presented, and the most complete experiments yet made upon it are recorded. Before the

formation of the Great Western Railway, the width adopted between the rails was 4 feet 8½ inches. Mr. Brunel at once signalized the undertaking committed to his care by adopting the gauge of 7 feet, being an excess over the previous width of 2 feet 3½ inches. The ends to be sought in the determination of the gauge appear to be,—adequate width for the machinery of the locomotive engine and for the carriages, so as to constitute them convenient and comfortable for travellers;—adequate width also for the conveyance of road-carriages and of general merchandize;—steadiness of motion, and safety and facility in passing round curves admitting a high rate of speed. These points are of course affected by the height (as determined by the size of wheels and construction) of the carriages and engines. While these considerations will determine the *minimum* width of gauge, there are others involving the expense of land, of wide bridges, viaducts, embankments, cuttings, stations, tunnels, &c., by which the *maximum* width must be limited. In the Report of Mr. N. Wood, above mentioned, and which is dated in December, 1838,[23] the reasons for the wide gauge are thus stated:

"From the documents previously alluded to, (Reports made by the Directors to the proprietary of the Great Western Railway,) from a careful perusal of Mr. Brunel's Reports, and from personal communications with that gentleman, the following appear to have been the prominent advantages expected to be derived from the increased width of gauge, and which induced the adoption of the width of 7 feet."

"*Attainment of a high rate of speed.*"—On this point Mr. Brunel remarks, "with the capability of carrying the line upwards of 50 miles out of London, on almost a dead level, and without any objectionable curves, and having beyond this, and for the whole distance to Bristol, excellent gradients, it was thought that unusually high speed might easily be attained; and that the very large extent of passenger traffic, which such a line would certainly command, would insure a return for any advantages which could be offered to the public, either in increased speed, or in increased accommodation."

"*Mechanical advantage of increasing the diameter of the wheels, without raising the bodies of the carriages.*—This comprehends what is deemed by Mr. Brunel the most important part of the advantage of an enlarged width of gauge, viz., the reduction of friction by the increased diameter of the wheels; while at the same time, by being enabled to place the body of the carriage

[23] Printed in the 'Civil Engineer and Architect's Journal,' vol. ii. p. 58.

within the wheels, the centre of gravity of the carriage is kept low, and greater stability and steadiness of motion are expected to be attained. Four-feet wheels have been put upon the carriages at present in use upon the line, but Mr. Brunel states, that he 'looks forward to the employment of wheels of a larger diameter; and that he has been influenced to a considerable extent in recommending the increased width of gauge, by its capabilities of prospective improvements which may take place in the system of railroads.' He observes, 'that though there are some causes which in practice slightly influence the result, yet practically the resistance from friction will be diminished exactly in the same ratio that the diameter of the wheels is increased; and considering that the gradient of 4 feet per mile only presents a resistance of less than 2 lbs. per ton, and that the friction of the carriages on ordinary railways amounts to 8 or 9 lbs. per ton, being $\frac{8}{10}$ths of the entire resistance, any diminution of the friction operates with considerably more effect upon a road with favourable, than one with more unfavourable gradients;' and he further says, 'I am not by any means at present prepared to recommend any particular size of wheels, or even any increase of the present dimensions. I believe they will be materially increased; but my great object would be in every possible way to render each part capable of improvement, and to remove what appears an obstacle to any great progress in such a very important point as the diameter of the wheels, upon which the resistance which governs the cost of transport, and the speed that may be obtained, so materially depend.'"

"*Admits all sorts of carriages, stage coaches, &c., to be carried within the wheels.*—Presuming that the adoption of wheels of a larger diameter is found beneficial, to the extent expected by Mr. Brunel, it became necessary that the carriages to be conveyed should be placed upon platforms within the wheels, to keep them as low as possible, which could not be done with carriages on railways of the ordinary width; a wider gauge seemed therefore necessary for this purpose."

"*Increased facilities for the adoption of larger and more powerful locomotive engines, for the attainment of higher rate of speed.*—Much stress has not been laid upon this by Mr. Brunel, although it has been alleged that great difficulties exist, and that considerable expense is incurred by being obliged to compress the machinery into so small a space; and consequently, that a greater width of gauge would enable the manufacturer to make a more perfect machine, and by having more space for the machinery, the expense of repairs would be lessened."

"*Increased stability to the carriages, and consequently increased steadiness of motion*, not from any danger to be apprehended, by the centre of gravity being higher in carriages of a less width; but that higher carriages are more liable to oscillate upon the railway, than carriages of a greater width and less height, and that a considerable part of the friction is occasioned by the oscillation of the carriages throwing the flanges of the wheels against the rails."

The objections which have been urged against the wide gauge are enumerated by Mr. Wood as follows:

"1st, The increased cost of forming the road track of the railway, in consequence of a greater width of base required for the superstructure of the rails and upper works. 2nd, That the carriages were required to be larger and heavier. 3rd, That the increased width of gauge caused additional friction in passing through the curves. 4th, That it entailed a greater expense of constructing the engine and carriages; increased liability to the breakage of axles, &c. 5th, That it prevented a junction of the Great Western with other railways; and 6th, above all, That there were no advantages gained commensurate with the increased expenses and inconvenience of such a departure and disconnexion from railways of the ordinary width; and several other objections which have been urged by different persons against the system, which it is not necessary to enumerate."

Mr. Wood then proceeds to describe the experiments instituted by him with a view to testing the validity of Mr. Brunel's reasons for adopting the gauge of 7 feet, and the objections urged against it by others. The results are stated as follows:

"We find, from the results previously enumerated, that a higher rate of speed has been obtained on the Great Western Railway than on other railways. This has been accomplished by the increased power of the engines employed on that railway above that of those on other railways: before, however, we can determine whether the increased gauge is, or is not, necessary, or best adapted for the accomplishment of this object, and to what extent, we must inquire whether engines of the power by which such performance was effected on the Great Western Railway, or such a power of engine as would accomplish that rate of speed, can be applied on railways of the ordinary width."

On this point the Report states, that "there are engines in use upon railways of the ordinary width, more powerful, in the proportion of 263 to 228, than an engine upon the Great Western Railway, which effects a rate of speed, within

3 miles an hour, of the most powerful engine on that railway. We have had no opportunity of subjecting these more powerful engines, on ordinary railways, to experiment, which would have been very desirable on the present occasion; but we find such engines, with an evaporating power of 165·26, effecting the same rate of speed on those railways, as the engine of 228·09 on the Great Western; and therefore the presumption is, that engines on railways of the lesser width of gauge, of the evaporating power of 253·21, or 263·8, would effect an increased velocity, quite equal to, if not greater, than that of the largest engine on the Great Western Railway."—"The inference which appears to me to result from these experiments is, that with engines of the same power, a greater result, and consequently a greater rate of speed, may be realized on the ordinary width, than upon the increased width of gauge of railway. If the object be to accomplish the greatest possible speed, a wide gauge is unquestionably better adapted for the construction of the largest possible engines, than the narrow gauge."—"The question, therefore, whether an increased width of gauge is or is not necessary, depends almost entirely upon the determination of what rate of speed it is advisable to attempt, or it is resolved upon to establish. If a mean rate of 32 miles an hour at full speed be sufficient for the purpose, or such increased rate as engines of the largest dimensions now in use on other railways can accomplish, then it will not be necessary, so far as the motive power is concerned, to increase the width of gauge. But if a greater rate of speed is required, the question assumes a different shape; and it must then be ascertained if an engine can be erected upon the lesser width of gauge to perform that rate of speed.

"If the object be the attainment of the rate of speed assigned by Mr. Brunel, (38 to 40 miles per hour,) the present engines, it will be seen by these experiments, cannot accomplish that performance, including all the vicissitudes of weather and other casualties; and, therefore, if a mean rate of speed of 40 miles an hour, including stops, is to be attempted, more powerful engines will be required.

"These experiments, however, show the immense sacrifice of power incidental to an extreme high rate of speed, or the accomplishment of a rate of 38 or 40 miles an hour, above that of 32 or 35 miles. If economy of conveyance is to be taken into consideration, it becomes a serious consideration whether such a system should be acted upon as that of providing for an indefinite rate of speed, or that a maximum rate should not be determined upon, and that

such standard should be composed of that speed which will best suit the public conveyance generally, and at the same time comprehend every possible economy and regularity."[24]

Upon the first advantage claimed for the 7-feet gauge by Mr. Brunel, that of increased speed, Mr. Wood's experiments go to show, that if a greater width than 56½ inches be promotive of this result, at any rate, that the engines then used on the Great Western Railway did not accomplish any greater proportionate speed than engines adapted for and used upon the narrow gauge. Among the conclusions resulting from these experiments are the following:

	London and Birmingham, 4′ 8½″ gauge.	Great Western, 7′ 0″ gauge.
Extreme rate of speed	40·9 miles ℔ hour.	45 miles.
With a load in tons of	34·5	50·0
Mean rate of speed in miles per hour	32 miles.	35 miles.
With a load in each case of	50 tons.	50 tons.
Estimated powers of evaporation stated in cubic feet of water evaporated per hour, and with a load of 50 tons in each case	163·87	288·28
Water evaporated per mile in cubic feet . . .	5·12	8·23
Consumption of coke per mile for each ton of the load, in pounds weight	·59	1·02

The engines here tried were the *Harvey Combe* on the London and Birmingham, and the *North Star* on the Great Western. The comparison between

[24] The wisdom of the course here indicated is made apparent by all recorded experiments upon the resistance to which moving trains are subject. The results of some recent experiments upon the Sheffield and Manchester Railway, reported by Mr. Scott Russell to the British Association for the Advancement of Science at their last meeting at York (1844), show, that while the resistance at slow velocities does not exceed 8 ℔s. per ton, it becomes equal to 19 ℔s. per ton at a velocity of 23·6 miles per hour. In descending planes this amount of resistance is reduced by the gravity of the moving mass, which, increasing with the load, enables heavy trains to descend with much less resistance and consequent diminution of velocity than light ones. Thus no greater resistance is encountered by a loaded train at 30 miles per hour, than by a light train at 23·6 miles per hour. The conviction of the truth of these results will, it may be expected, lead to more moderate expectations as to speed than have commonly prevailed since the successful introduction, or rather improvement, of the locomotive steam engine. Professional experience has already dictated an ordinary speed much below that obtained upon extraordinary occasions, when *cost* of power has been temporarily disregarded.

the *Harvey Combe* and the *Æolus*, (another of the wide-gauge engines,) however, shows the performance of the latter in a still less favourable light than those of the *North Star*. The *Æolus*, with estimated powers of evaporation of 228·09 cubic feet of water per hour, consuming ·76lb. of coke per ton per mile, carrying only an equal load of 50 tons with the *Harvey Combe*, maintained a mean rate of speed *less* by ·4 mile per hour than the latter engine!

In replying to this Report, Mr. Brunel stated that "experiments have since been made, giving very different results, and I can prove that if an engine be properly constructed for high speeds in the manner which I have always proposed, that there is no such 'immense sacrifice of power incidental to an extreme high rate of speed, or the accomplishment of a rate of 38 or 40 miles per hour, above that of 32 or 35 miles,' and that the same engine, which was then only capable of taking 40 tons at an average velocity of 38 and a maximum of 41½ miles per hour, is now capable of taking 40 tons at an average velocity of 40 miles per hour; and further, that the consumption of coke per ton, so far from being extravagant, is not so great as that of the engines on the London and Birmingham Railway, when only travelling at a mean rate of 30 miles per hour." The experiments on which these assertions were based do not appear to have been published or in any manner detailed to the public.

On the "mechanical advantage of increasing the diameter of the wheels without raising the bodies of the carriages," the second alleged advantage of the 7-feet gauge, examined by Mr. Wood, he suggests the difficulty of deducing any definite conclusions. This appears to arise from three doubtful data, which Mr. Wood's experiments did not enable him to determine, viz.: 1, The proportion of the total resistance due to atmospheric agency, and to mechanical friction; 2, The increased atmospheric resistance encountered by large wheels over small ones; and 3, The proportion in which these resistances operate at high rates of speed. Mr. Wood, however, considered that his experiments did sanction the assumption that of the whole resistance encountered at a speed of 32 miles an hour, 22 per cent. only is due to friction, and 78 per cent. to atmospheric resistance. As it is this 22 per cent. only, which it is alleged may be reduced by large wheels, while it seems moreover probable that the 78 per cent. may be somewhat *increased* by them, the possible benefit accruing from their adoption is reduced to a very trifling amount.

The third benefit stated, as to the admission of carriages, &c., between the

wheels, being a desideratum only when wheels are used of too large a diameter to allow the truck to project over them, as is commonly done with the narrow gauge, does not call for any examination until the advantage of the large wheels is determined.

The claim of the fourth advantage, viz., facilities for using more powerful engines on the wide gauge, seems sufficiently answered by the performances already quoted of the London and Birmingham and Great Western engines. Indeed, Mr. Wood stated in his Report, that Messrs. Stephenson had then (six years ago) constructed an engine for the Leicester and Swannington Railway (4′ 8½″ gauge), having an evaporating power of 263·8, only 25·20 cubic feet of water per hour less than the most powerful engine at that time built for the Great Western Railway. And the subsequent improvements in the wide engines have certainly not outstripped those of the narrow ones so as to reduce this proportion in their favour.

"The remaining proposition," says Mr. Wood, "is, that a wider gauge affords increased stability to the carriages, and consequently, increased steadiness of motion. The diagrams given will show how far this has been effected on the present portion (22½ miles) of the Great Western Railway, and certainly these documents would prove that this has not yet been accomplished. Considering, however, the causes of the different motions of railway carriages, there can be no doubt that an increased width of gauge must tend to produce that effect. In the present instance this has been counteracted by the construction and present condition of the road and carriages; and therefore it appears to me the only conclusion we can come to is, that in similarly-constructed railways the wide gauge will afford greater stability and steadiness of motion to the carriages." General observation of the motion upon the Great Western Railway, will, it is believed, confirm the fact of its greater steadiness, although probably only a part of this result is attributable to the width of gauge, something being due to the construction of the railway upon continuous wooden sleepers, to the easy gradients, and the great radii of the curves.

The six objections quoted by Mr. Wood may be thus disposed of:—First, the increased cost of forming the road track must be admitted, although this would appear to be trivial; according to Mr. Brunel, while the difference in width of land, of embankments, cuttings, viaducts, and tunnels, does not seem necessarily great between the requirements of the narrow and the wide gauge. Mr. Brunel, in his Report to the Directors in 1838, states,—"a 7-feet gauge

requires no wider bridge or tunnel than a 5-feet; the breadth is governed by a maximum width allowed for a loaded waggon, or the largest load to be carried on the railway, and the clear space to be allowed on either side beyond this. On the Manchester and Liverpool Railway, this total breadth is only 9 feet 10 inches, and the bridges and viaducts need only have been twice this, or 19 feet 8 inches. Nine feet 10 inches was found, however, rather too small; and on the London and Birmingham, with the same width of way, this was increased to 11 feet by widening the interval between the two railways.

"In the space of 11 feet allowed for each rail, a 7-feet gauge might be placed just as well as a 5-feet, leaving the bridges, tunnels, and viaducts exactly the same; but 11 feet was thought by some still too narrow, and when it is remembered that this barely allows a width of 10 feet for loads, whether of cotton, wool, agricultural produce, or other light goods, and which are liable also to be displaced in travelling,—13 feet, which has been fixed upon in the Great Western Railway, and which limits the maximum breadth, under any circumstances, to about 12 feet, will not be found excessive. It is this, and not the increased gauge, which makes the minimum width actually required under bridges and tunnels, 26 feet instead of 22 feet.

"The earth-work is slightly affected by the gauge, but only to the extent of 2 feet on the embankment, and not quite so much in the cuttings; but what in the practice has been the result? The bridges over the railway, on the London and Birmingham, are 30 feet, and the width of viaducts 28 feet. On the Great Western Railway, they are both 30 feet: no great additional expense is therefore incurred on these items, and certainly a very small one compared to the increased space gained, which, as I have stated, is from 10 to 12 feet. In the tunnels exists the greatest difference. On the London and Birmingham Railway, which I refer to as being the best and most analogous case to that of the Great Western Railway, the tunnels are 24 feet wide. On the Great Western Railway, the constant width of 30 feet is maintained, more with a view of diminishing the objections to tunnels, and maintaining the same minimum space which hereafter may form a limit to the size and form of every thing carried on the railway, than from such a width being absolutely necessary.

"Without pretending to find fault with the dimensions fixed, which have no doubt been well considered upon the works on other lines, I may state that the principle which has governed me, has been to fix the minimum width, and to

make all the works the same, considering it unnecessary to have a greater width between the parapet walls of a viaduct, which admits of being altered, than between the sides of a tunnel, which cannot be altered.

"The embankments of the London and Birmingham Railway are 26 feet—on the Great Western, 30 feet; making an excess of about 6½ per cent. on the actual quantity of earth-work.

"The difference in the quantity of land required, is under half an acre to a mile. On the whole, the increased dimensions from 10 to 12 feet will not cause an average increased expense in the construction of works and purchase of land, of above 7 per cent.,—8 per cent. having originally been assumed in my Report, in 1835, as the excess to be provided for."

The extent to which the second objection, that of the increased weight of the carriages, prevails is this:—a Birmingham first-class carriage weighs 3 tons 17 cwt. and 2 qrs.; a Great Western first-class weighs 4 tons and 14 cwt. The one, however, carries 18 passengers, while the other carries 24 passengers. While the weight on the four wheels is thus made greater on the Great Western than on the London and Birmingham, the gross weight per passenger is less in the former than in the latter case, being as 588 to 631 lbs.

The 3rd objection, the greater friction produced in passing round curves, must be allowed its full force, as a general principle, although in the case of the Great Western Railway, it is much alleviated by the great radii of all the curves.

The 4th objection is of little weight, and practically the liability to breakage of axles from their increased length is not found to exist. The applicability of the 5th will depend upon the position of the railway, whether destined to be isolated from or connected with other lines of which the gauge is already determined.

There is another objection, suggested by the results of the experiments made upon the resistance offered by the atmosphere, which ought not to be overlooked, viz., the increased resistance occasioned by the greater size of frontage of carriages and engines adapted for the 7-feet gauge. The Report already so largely quoted from does not detail any experiments with carriages for the wide gauge; but as the resistance doubtless increases in the same proportion as the area of frontage, and this area is as 81 to 53 for the two gauges, the resistance arising from the atmosphere must be supposed to be much increased by the adoption of the wide gauge.

The 6th and last objection, viz., that the 7-feet gauge realizes no advantages commensurate with the increased expense and probable inconvenience connected with its adoption, amounts practically to a denial of all the reasons assigned by Mr. Brunel in favour of it; yet it appears that Mr. Wood's opinion that this objection is substantially confirmed by the results of experience, is correct, although there are some advantages gained by an increase of gauge beyond 4 feet 8½ inches, which well deserve attention in planning lines for new countries, or lines that will be beyond the liability to connexion with others already executed to that gauge. It is a curious fact connected with this subject, and illustrative of the commercial value of uniformity of gauge, that the entire of the Eastern Counties, and Northern and Eastern Railways, as yet executed, comprising about 85 miles of line, have recently been altered from the gauge adopted in their formation (5 feet), to the more general gauge of 4 feet 8½ inches,—thus involving a tremendous expense, not only in this alteration but in others depending upon it, viz., width of carriages, engines, &c., in order that these lines may eventually be susceptible of connexion with the northern lines already made to the narrow gauge.

Tredgold treated the subject of gauge thus:

"The breadth of the track ought to have some relation to the height of the load, in order that the carriage may be always in stable equilibrium on the rails; and in railroads there is another circumstance to be considered,—the pressure on the rails should not be materially altered by any slight depression of one side of the road. It may be taken as a general rule, for the width between the rails for carriages travelling at a greater speed than 5 miles per hour, that the centre of gravity should not be higher in proportion to the breadth between the rails than as 1 is to 1½."—"The width between the rails being therefore dependent on the height of the centre of gravity of the loaded carriages, and this again varying with the nature of the load and the velocity, it will be obvious we cannot do better than make the breadth between the rails such, that, by disposal of the load, the centre of gravity may be kept within proper limit in either species of vehicle, whether swift or slow. And it would be desirable that the same breadth and the same stress on a wheel should be adopted in all railways. We would propose 4 feet 6 inches between the rails for heavy goods, and 6 feet for light carriages, to go at greater speed." [25]

[25] 'A Practical Treatise on Railroads and Carriages,' by Thomas Tredgold. Second edition, 1835, p. 118.

We have at present three widths of gauge in England, viz., 4 feet 8½ inches, 5 feet, and 7 feet: two others in Scotland, viz., 4 feet 6 inches, and 5 feet 6 inches; and one yet different from any of these in Ireland, viz., 6 feet 2 inches.

In concluding these preliminary considerations of curves, gradients, and gauge,—subjects which are held to involve so much of the current economy and commercial success of our railways,—the following Table, which has cost some pains in its compilation, may be presented as embodying some interesting facts appertaining to each of nine railways, and showing generally the value of each line, both to the proprietors, in interest for their expended capital, and to the travelling public, in rapid and economical means of conveyance.

	A.	B.	C.		D.	E.	F.			G.	H.
					According to the latest balance-sheets.						
Name of Railway.	Curves.	Gra-dients.	Gauge.		Cost of working for six months, per mile.	Returns for six months, per mile.	Dividend per cent. per annum.			Velocity, average miles per hour.	Charge, average pence per mile.
			ft.	in.	£.	£.	£.	s.	d.		
1. Dundee and Arbroath	very slight	nearly level	5	6	183	430	5	0	0	W. 21	1·45
2. Grand Junction	medium	second class	4	8½	810	1875	10	0	0	22·14	2·29
3. Great Western	very slight	first class	7	0	595	1666	7	0	0	25·80	2·14
4. Liverpool and Manchester	medium	third class	4	8½	1861	3823	10	0	0	W. 23·93	2·53
5. London and Croydon	slight, but all curved	second class	4	8½	739	1028	2	10	0	W. 20·78	1·17
6. London and Birmingham	slight	first class	4	8½	825	3606	10	0	0	24·50 or 22·14	1·93
7. London & South Western	medium	second class	4	8½	736	1617	6	10	0	21·81 or 20·26	2·28
8. Newcastle and Carlisle	severe	second class	4	8½	429	1197	4	0	0	19·42	1·89
9. North Union	medium	second class	4	8½	258	1021	6	16	8	W. 22·0	2·03

The Table consists of eight columns, lettered A to H. Of these, three may be regarded as exhibiting the constructive peculiarities; three, the commercial; and, two, the public features of each line. Thus, columns A, B, and C, describe the *curves*, *gradients*, and *gauge;* columns D, E, and F, show the cost, per mile, of working the railway for six months,—the returns, per mile, for the same period of six months,—and the dividend, per cent. per annum, paid to the shareholders. All these three items are given according to the latest balance-sheets of the respective companies. Columns G and H show the average velocity in miles, per hour, of the four, five, or six daily trains on each line, and including all stoppages. For the London and Birmingham, and the South Western Lines, two rates of velocity are quoted: the first or greatest rate, is excepting the one daily slow third-class and goods train; the second or least rate, is inclusive of this train, which being taken into account, greatly reduces the average velocity. Still it appears but fair that this reduced rate should be adopted as the average. The public, consisting of *all* classes, is assumed to be interested in the *general* average velocity; the working man's eight hours are at least as valuable to him as the rich man's five hours are to those who can afford to pay higher fares; and those railway companies who find it economical or deem it politic to distinguish thus between their customers, cannot be considered as affording equal accommodation with those who do not. Column H shows the charge in pence and decimal parts made by each company, per passenger, per mile, on the average of the two or three classes of fares, as the case may be, charged by each.

The terms used in column A, as descriptive of the curves, are merely comparative, and cannot be fixed as indicative of any precise limits of curvature. The classification adopted in column B is according to that suggested by Mr. Whishaw, calling all gradients not exceeding 16 feet per mile, or 1 in 330, the *first class;* those not exceeding 52·80 feet per mile, or 1 in 100, the *second class;* and those not exceeding 80 feet per mile, or 1 in 60, the *third class.* This mode of distinguishing is, however, inadequate to exhibit the *general* character of the gradients. This could perhaps be effected by multiplying together the length and the rate of inclination of each gradient; combining these throughout the entire line, and balancing this compound quantity of inclination against the lengths of the level planes united. Yet many reasons will occur to show that this would by no means express the relative goodness or badness of the gradients as likely to affect the beneficial

working of the railway. The cost of working, returns, and dividend, are quoted from the documents published in the 'Railway Times' weekly paper. The velocity and charge are from the Time and Fare Tables published under authority of the several companies; except in the four instances marked 'W.' In these cases, the Time Tables not containing the required information, the authority has been taken from Mr. Whishaw's experiments, published in his work on Railways.

By this Table only an approximate comparison is attempted to be drawn between the several railways named upon the various points indicated in the columns. No statistics of this kind probably would warrant any very definite principles as to the construction or the management of a railway. It is not found that the velocity, or the fares, or the current expenses, or the average returns, vary in any assignable ratio according to the curves, the gradients, or the gauge. Although the general principles which are indicated by the evidence cited in the preceding pages are applicable in each individual case, their results are comparable only *cæteris paribus*, and as this condition of things seldom or never exists, no such comparison can serve as a practical test of the general rules observed. Its real value consists in the proof it affords that the discretion of the engineer cannot overcome, although it undoubtedly modifies, those causes of expense and difficulty in construction which belong naturally or locally to the routes which he is required to adopt.

Slopes.—On this point of railway practice, beyond stating the evident principle that the inclination of the slopes must be determined mainly by their height and by the nature of the material excavated, or of which the embankment is composed, we propose merely to quote the slopes adopted by the engineers of some of the British railways already formed, reserving for the Second Section, upon Earth-works generally, such statements and descriptions of their construction and mode of treatment as appear desirable.

Birmingham and Gloucester.—The cuttings are chiefly through marl and lias clay. The greatest depth excavated is 85 feet (at Moseley), sloped at $1\frac{1}{2}$ to 1; that is, $1\frac{1}{2}$ length of base to 1 in vertical height. The highest embankment is 62 feet, sloped at 2 to 1.

Chester and Birkenhead.—For heights under 35 feet, the slopes are $1\frac{1}{2}$ to 1, and 2 to 1 above that height, the slopes being soiled and sown with grass-seed.

Durham and Sunderland.—A cutting, 60 feet deep, sloped at $1\frac{1}{2}$ to 1, through

loose clay and sand, has occasioned considerable expense and trouble in attempts to prevent the sides slipping in.

Great Western.—A cutting east of the Brislington tunnel, of considerable depth, containing 30,000 cubic yards, has vertical sides.

London and South Western.—The slopes vary from 1 to 1, to 2 to 1, according to the strata, which consist generally of loam, gravel, sand, London clay, and flints with chalk.

Midland Counties.—The greatest depth of the Leir cutting is 62 feet, sloped at 2 to 1; the Leir embankment, 40 feet high, is formed with similar slopes.

Newcastle and Carlisle.—The Corvran Hill cutting is through clay with veins of sand intermixed; the average depth is 43 feet; greatest depth 110 feet; sloped $1\frac{1}{2}$ to 1.

Newcastle and North Shields.—Cuttings through stratified clay are sloped from 2 to $3\frac{1}{2}$ to 1; through unstratified, $1\frac{1}{2}$ to 1. The embankments, formed mainly of small coal, are sloped from $1\frac{1}{2}$ to $2\frac{1}{2}$ to 1.

North Union.—Slopes for cuttings and embankments, if very trifling in depth or height, 1 to 1; if 15 feet, $1\frac{1}{2}$ to 1; and exceeding 15 feet, 2 to 1.

Slamannan.—Cuttings through hard blue clay, 16 to 40 feet deep, have slopes at 2 to 1. Embankments 40 feet high, formed with same slope.

South Eastern.—The Leigh cutting, through hard white sand with some marl, sloped at $1\frac{1}{2}$ to 1. The River Medway embankment at 2 to 1.

Ulster.—The material excavated and used for embanking is a loose slippery clay, and although the slopes are 2 to 1, much difficulty was experienced in preventing their failure.

SECTION II.

EARTH-WORKS, CUTTINGS, EMBANKMENTS, AND DRAINS.

The course and section of the railway, and the width of surface required, being determined, those operations included under the title of this Section claim the first attention of the engineer in proceeding to form his line.

Some geological examination of the materials he will have to deal with may be supposed to have aided the engineer in determining his slopes, and this also must dictate the kind of arrangements that will be necessary for draining the railway. Thus, all stratified materials occurring in layers having an inclination

to the horizon are liable to a slipping of one stratum from another, which makes it necessary that all slopes through these strata should be much less steep than would be safe in unstratified materials. These slippings, caused by the passage of water, or the action of frost between the strata, must also be sought to be prevented by draining the faces of the cutting, and extending the drainage also backward for some distance, so as to collect all the water that may find its way into the neighbouring soil, and conduct it safely away before it arrives on the face of the work. A complete superficial drainage must also be provided for the water that may collect upon the surfaces of the cutting. Alternating strata of sand and clay are perhaps the very worst that can occur to the railway engineer. Soils having these same materials *mixed* are much more favourable and safe. Stony soils, or those composed of sand and gravel mixed, also become very compact and hard. Through rocks, excavations may be formed with very steep sides, although if the rocks be of a kind that is liable to disintegration by moisture, a greater flatness, which exposes the sides to the evaporating action of the sun and air, becomes desirable.

Chalk is one of the materials whose own cohesion is sufficient to keep it together if cut with faces vertical or nearly so. From some observations on chalk excavations by Mr. S. Hughes,[26] the following extracts may be usefully quoted:

"A great deal of discussion arose during the struggle between the various Brighton lines, in the session of 1837, as to the best method of forming the chalk excavations. It was argued by one party that a slope of from $\frac{1}{2}$ to 1, to 1 to 1, should be adopted for the cuttings; while another proposed to make the sides nearly vertical, contending that a slope of $\frac{1}{6}$ to 1 was sufficient. A third party proposed a system of benching at about every 15 feet in height, the successive steps to be vertical, and to be faced with rock-chalk."

Plate I. Fig. 1 represents the two latter of these suggestions, the left-hand half of the excavation showing the method of uniform slope proposed by Mr. Rastrick; the right-hand showing the system of benching and facing suggested by Mr. Gibbs.

"The South Foreland is a very remarkable face of chalk, which appears at a distance to be nearly vertical, but on approaching more closely is found to slope about $\frac{1}{3}$ to 1. The height is about 350 feet, and a considerable quantity

[26] Printed in the 'Civil Engineer and Architect's Journal,' vol. ii. p. 207.

of *débris* has fallen to the base of the cliff. In the neighbourhood of Chatham are several chalk excavations, but none so extensive as those at Dover. East of the town, on the road to Maidstone, a cutting of about 30 feet in depth stands nearly vertical. In the fortifications of Chatham, most of the chalk, as at Dover, is faced with brick-work. One excavation, however, forming a gorge from the river to the crest of the works, has been cut for some distance without facing, with a slope of $\frac{1}{3}$ to 1, in depth about 40 feet; another part of this gorge is faced with brick, the same slope being preserved."

Mr. Hughes states his belief of the greater cohesion of the upper beds of chalk as follows:

"From almost every instance I have been able to observe, I think it clear that the upper chalk with flints, when not much shaken, really will stand upright without scaling. At the same time it is no less certain that, below a particular depth, the chalk undergoes a very apparent and extensive decomposition, and in many cases presents a base visibly hollowed out.

"It is hardly in accordance with hitherto received opinions on the subject of chalk cuttings, to say that these will stand better in their upper than their lower beds, and yet the result of every observation made on the chalk of Kent, leads positively to the conclusion that the superior beds of chalk are less subject to decomposition than the lower. Instances in proof of this may be seen at Dover, particularly on the eastern side of the town; at Chatham, in the military works; at Rochester, and the other entrance of the Thames and Medway tunnel; and at the quarries of Northfleet and Greenhithe."

Respecting the chalk excavations on the line of the London and Birmingham Railway, it is stated,—

"The chalk of Watford tunnel is very soft and white, with numerous layers of flint, and much saturated with water, in which respect it differs from all the former kinds of chalk I have described,—these being all remarkably dry, at least as deep as they have hitherto been explored. At the northern end of Watford tunnel is the same soft white chalk with flints. The slope from the base is $\frac{3}{4}$ to 1, until within 15 feet of the surface, when the slope is increased to $1\frac{1}{2}$ to 1. The cutting near Cow Roost consists also of very white chalk, much saturated, and the slopes are $1\frac{1}{2}$ to 1, in 25 feet cutting. Further on the line, in a cutting near the road from Tring, the lower grey chalk occurs in moderately sized blocks. The cutting at the north end of the short Tring tunnel consists of chalk, chalk-marl, and a little gravel. The slope, which is

$\frac{3}{4}$ to 1 in 35 feet cutting, stands well, and the chalk appears drier than in some of the cuttings nearer London.

Figs. 3, 4, and 5, Plate II., illustrate one of the most interesting works on the London and Birmingham Railway, viz., the excavations at Blisworth. The principal excavation appears, by the sections published in the 'Public Works of Great Britain,'[27] to be about 126 chains in length, the greatest depth 53 feet. The strata intersected are—the upper soil, of a light sandy kind, with clay from 2 to 10 feet in thickness, and lying mainly in blue, yellow, and brown marl and red clay, of an average thickness of 20 feet. Under these is the limestone rock of various degrees of hardness, and in beds of 1 to 4 feet in thickness, but without any mixture of shale, and having springs of water in the lower beds. At the east end of the section, the limestone rock outcrops, and the superior stratum of marl disappears. Beneath the limestone the blue shale is found; it appears to be dished on the upper surface, being about 6 feet thick at the east end, extending about 20 chains, then ranging beneath the railway level, rising again at the end of 75 chains, and acquiring a thickness of nearly uniform increase of 30 feet at the western extremity of the section, where it outcrops beneath the limestone.

At the west end, the excavation is formed to a slope of 2 feet base to 1 foot height, throughout its whole depth, for a distance of 22 chains, the inferior stratum of shale being faced with rough stones. Through the next distance of 38 feet, the opening is narrowed by a winding batter[28] on each side to a section corresponding with that shown in fig. 3, Plate II. The lower part, extending upward to a height ranging with the undersetting of masonry, beneath the rock, which is continued throughout the excavation, is formed to a curved batter of 106 feet radius. The average vertical height of this undersetting above the level of rails is 20 feet. The rock above is sloped at $\frac{1}{4}$ to 1, a benching of 9 feet wide being left on its upper surface, and the superior soil trimmed to a slope of 2 to 1.

The figures 3, 4, and 5, Plate II., also exhibit the mode of draining adopted, with the inverts and buttresses for supporting the undersetting. Fig. 3 is a

[27] Edited by Mr. Simms, and published by J. Weale. 1838.

[28] The French verb "bâtir," substituted by some engineers, seems no more expressive of the understood meaning of this term than the word batter, here used. We therefore retain the more common word.

cross section, one-half being taken through the wall, the other through one of the buttresses: fig. 4 is a sectional plan of half of the excavation, showing the recess wall, 2 feet 6 inches thick at top, battered in front to a slope of 2 inches to 1 foot. The centre drain, 1 foot 9 inches wide, and the cross drains, are shown in section. Fig. 5 is a longitudinal elevation of the undersetting, showing two of the buttresses with the inverts beneath in section. Midway between each two contiguous buttresses, a vertical drain or gullet is formed on the face of the wall, receiving the drainage water by oblique drains, shown in dotted lines from the puddling at the back of the wall.

The following extracts from the Engineer's Specification for this work, which will be found at length, illustrated by several magnificent folio plates, in the 'Public Works,' will explain the remaining particulars. "Wherever the shale or other soft strata lying under the limestone is found to rise above the level of the bottom of the cutting, a portion of such shale or soft strata shall be excavated from under the limestone on each side of the cutting, and replaced by walls, buttresses, arches, and inverts, as hereinafter described. The inverts to be of an invariable width of 27 feet, and to have a rise of 3 feet 3 inches, the radius being 29 feet 8 inches; the junction of which inverts with the face of the buttresses, to be always at the level of the surface of the rails. The back of the buttresses to batter outwards from the centre of the cutting at the rate of $\frac{3}{4}$ inch horizontal for 1 foot in height, as shown in the section; and the sides of the buttresses to batter out at the rate of 1 in 20 on each side, as shown in the plan and elevation. The recess walls to have the same batter at the back, corresponding with the buttresses, and the face of such walls to have a straight batter of 2 inches in 1 foot. These walls shall have three courses of footings of 1 foot each in depth, each course to step 6 inches. The bottom of the walls to be level with the bottom of the inverts and buttresses.

"At a depth never falling short of 1 foot below any wet stratum that may occur, two courses of the recess wall and buttresses to be projected beyond the back of the wall; the lower course to project beyond the upper, so as to receive a stone to rise 1 foot above the upper course, forming a drain 12 inches deep and 6 wide, to be surrounded at the bottom and back with a casing of sound puddle, and filled in at top with rubble stone, to allow the top water to have access to the drain." (This is shown on the cross section, Plate II. fig. 3.)

"When the depth of the shale from the bottom of the rock to the bottom of

the cutting shall be less than 14 feet, then the inverts between the buttresses shall be discontinued; and in lieu of the inverts, the buttresses shall have four courses of footings, when the depth of shale above the bottom of the cutting exceeds 10 feet, and three courses for all lesser depths. Further, when, as aforesaid, the shale, or clay, or other soft material, rises to the height of 10 feet above the bottom of the cutting, then the level of the bottom footings of the buttresses shall be 3 feet 3 inches below the said cutting, which depth shall decrease proportionally as the above height diminishes, until the rock meets the level of the bottom of the cutting."

The following account of some of the interesting earth-works on the Dublin and Kingstown Railway is extracted from the work of Mr. Whishaw already quoted. "Beyond Merrion the railway is carried by a sea embankment, which extends uninterruptedly to Blackrock. This embankment is about 50 feet wide, on a level with the rails, and about 95 feet at the base; the height being about 12 feet. It is chiefly formed from side-cuttings in the sand contiguous to the work, the whole being covered with a mass of earth, gravel, and rubbish taken from the shore. The face of the embankment is paved throughout with stones of from 1 to 12 cubic feet each, the whole being laid with a slope of 3 to 1. The foundation is carried down about 2 feet below the level of the sand; and the parapet, which is 2 feet 3 inches thick on the top, and 2 feet thick at 1 foot from the top, is finished as to its face, in the form of a parabolic curve, the object of which is to prevent the sea from washing over the railway. This parapet is 3 feet 6 inches in height. There is a cutting opposite to Blackrock House, the depth of which is about 36 feet, and the length about 7 chains, the slopes being formed at $\frac{1}{2}$ to 1. The railway is again carried over the strand by a similar embankment to that already described."

The heavy earth-works upon the line of the North Midland Railway are thus described in the same work. "Among the principal works in this department may be mentioned the Oakenshaw and Normanton cuttings. The Oakenshaw cutting is in rock shale and bind, the greatest depth of which is 50 feet, and its contents amounted to 600,000 cubic yards, the greater proportion of which was led to form the Oakenshaw embankment, the average lead being about 1 mile, and the cost being at the rate of 1*s.* 7½*d.* per cubic yard, and of that carried to spoil, 1*s.* 4*d.* per cubic yard. The Normanton cutting is 55 feet at its greatest depth, and contained 500,000 yards, chiefly of rock and blue bind, the produce of which was for the most part led to form

the Altofts embankment, and 70,000 yards thrown out to spoil, the average lead being 1½ mile, and the cost per yard 1*s.* 3*d.*, and of that carried to spoil, 10*d.* The slopes of cuttings are generally formed at 1 to 1, and of embankments at 1½ to 1. The whole width of cuttings is 33 feet, the top width of embankments 36 feet, and on the top surface of ballasting 26 feet. The works were let throughout (72·50 miles) in upwards of thirty contracts, varying in length from ½ a mile to 4¼ miles. The progress of the works in 1839 was so rapid, that not fewer than 450,000 cubic yards of excavation were effected per month, and the number of men employed amounted to about 8600; besides which there were 18 fixed engines, working chiefly at the tunnels."

On the Stockton and Hartlepool Railway, it is stated that "the total amount of cuttings is 340,000 cubic yards, (the length of the line is 8·175 miles,) or upwards of 41,000 cubic yards per mile. For some distance the line runs close to the sea; and here the seaward slope, or face of the embankment, is of curvilinear form, and constructed of well-puddled clay, being united with the solid clay which underlies the sand. Its stability has already been subjected to repeated tests during many very heavy seas, which have washed over it again and again; but yet it continues to stand well, and a considerable quantity of sand and shingle are already deposited at the base of the slope."

The celebrated example of Chatmoss, on the Liverpool and Manchester line, where Mr. George Stephenson contrived, at a cost below the average of other parts of the line, to get a secure foundation for the passage of the locomotive engines and heavy trains over a moss containing nearly double its bulk of water (670,000 cubic yards of raw moss forming only 277,000 yards of moss-earth), is thus described in Lecount's 'Practical Treatise on Railways,' 1839, page 46: "The depth of the moss varied from 10 to 34 feet, and its general character was such, that cattle could not walk on it; the subsoil was principally composed of clay and sand, and the railway had to be carried over it upon a level, and required cutting and embankment for upwards of 4 miles. Where the mode of doing this required an embankment, the expense of which, in the ordinary method, would have been enormous, as it must have been bottomed upon the subsoil of the moss, Mr. Stephenson contrived to use the moss itself in the following manner. Drains about 5 yards apart were cut, and when the moss between them was perfectly dry, it was used to form the embankment, and so well did it succeed, that only about four times the quantity was required that would have been necessary on hard ground. Where the road was on a

level, drains were cut on each side of the intended line, by which, intersected with cross ones occasionally, the upper part of the moss became dry and tolerably firm: on this, hurdles were placed, either in double or single layers, as the case required, 4 feet broad and 9 feet long, covered with heath; on these was laid the ballast, and the method was fully successful. Longitudinal bearings, as well as cross sleepers, were used to support the rails where necessary, and the whole was thoroughly drained. In the cutting, the whole had to be accomplished by drainage entirely. Longitudinal drains about 2 feet deep were cut on each side of the intended line of railway, and when by this means the upper portion of the moss had become dry, about 12 or 15 inches in depth were then taken out, as in an ordinary case of excavation; the drains were then sunk deeper, and another portion taken out when dry, as before; and thus, by alternately draining and excavating, the depth required for the railway was attained, which in some instances was 9 feet, the embankments being as high as 12 feet. The only advantage in favour of these operations was, that the surface of the moss was higher than the surrounding country, which partially assisted the drainage; but when it is considered that, from the nature of the ground, an iron rod would sink by its own weight, it must be confessed that such an undertaking as carrying a railway along, under, and over such a material, would never have been contemplated by an ordinary mind. In a smaller moss, which had also to be crossed, and which was about 20 feet deep, although an embankment of only 4 feet high was required, the clay and gravel tipped amounted to as much as would form one 24 feet high on ordinary ground."

Figs. 1 and 2, Plate II., illustrate an economical method of forming embankments and cuttings in districts where stone is plentiful, and which has been advantageously adopted on the Leeds and Selby and other lines. This consists in facing the embankment or the lower part of the cutting with rough stones, built in the rubble fashion, and with a batter sufficient to insure its stability. As adopted on the Leeds and Selby line, this facing to the embankments has a curved batter, the chord line of which forms an angle of 67° 30′ with the horizon. Embankments thus formed require to have strong parapets, as otherwise any deviation of the train from the rails would certainly be attended with terrible consequences. Where this occurs on the edge of an embankment formed of soil and sloped at 2 to 1, or thereabouts, the chances are great that the train is speedily arrested by sinking in the yielding material; but with

embankments faced in this manner with steep sides, the least progress beyond the edge must inevitably overthrow the train. The great advantages of the method are, economy in quantity of earth-work to be embanked and in width of land required; also in facility of drainage, and consequent stability and durability. An open longitudinal drain or channel being formed behind the parapets, and made to communicate with vertical or oblique channels formed on the face of the stone-work, will conduct the whole of the water to the toe of the embankment, whence it is readily withdrawn by side ditches. Against these advantages, have to be considered, the increased chance of danger from the cause just explained, and the somewhat greater amount of labour, and of a more expensive kind, required in the construction. Applied to cuttings, this system of facing is free from the first of these objections, while its utility in economizing labour in excavating is much greater. A little consideration will show that the faced embankment saves only a triangular section on each side, while the faced cutting saves a trapezoidal section of nearly double area. The slope of the earth-work above is very efficiently drained by a longitudinal channel behind the top of the facing, connected either with channels on the face or perpendicular drains behind, with cross drains leading into the centre one, as shown in fig. 2.

Figs. 6, 7, 8, 9, and 10, Plate II., represent the mode of forming cuttings and embankments adopted on the London and Birmingham and other railways. Fig. 6 is a half-section of an embankment, slopes 2 to 1; top width on formation-line, that is, below the ballasting, 33 feet; gauge 4 feet 8½ inches; central width between the two lines 6 feet. The slope is turfed. A bank and rail-fence skirt the bottom of the bank, and beyond there is an open ditch, 3 feet wide at top. Fig. 7 is a half-section of a cutting of a similar formation,—same slope, formation, width, gauge, &c. The upper edge of the cutting is guarded by a rail-fence on a bank; and the adjacent land is drained by an open ditch beyond, 5 feet wide at the top, 2 feet at bottom, and 1 foot 6 inches deep. Figs. 8 and 10 are enlarged views of the fences and ditches for cuttings and embankments, with ditches of different dimensions, and the posts being strengthened with spurs and struts. Hedges of quickset are planted within the fences. Fig. 9 shows a desirable method of protecting the toe of an embankment by a low underset wall of masonry, formed with a considerable batter. Another method of effecting the same purpose has been also advantageously applied, and is recommended by its cheapness. This is to erect a mound of

earth skirting the lower edge of the bank, which, becoming consolidated, forms a good permanent ridge to prevent the bank spreading.

The stability of earth-works, both embankments and excavations, being so much aided by making their sides sufficiently flat, also requires that they be not too flat. The angle formed by the slope with the horizon must not exceed the angle of repose of the material: indeed, to provide for the shifting tendency of water forcing its way through the mass, and other operating causes, and, in embankments, the spreading effect of passing weights, the slope should be kept within that of the repose of the material; but on the other hand, every degree of unnecessary flatness is prejudicial (beyond being expensive in land, in material, in labour, and in time), by exposing a greater surface for the disintegrating action of the atmosphere and the weather, and impeding the efficiency of the drainage. Of course the sides of the work should be sufficiently flat to be acted upon by the sun and the wind, by which all external moisture is evaporated and the surface hardened; but in general it will be found that an angle a few degrees less than that of repose will be found to answer both the conditions of economy and stability; and a little extra attention in drainage will be found cheaper than giving additional flatness to the slopes. The banks are much preserved by covering them with turf or the surface-soil, (which should be taken care of for that purpose,) and afterwards sowing this with grass-seed. Spade-cuts, or channels, passing obliquely from the summit of the slope to the drain at the base, so as to form a repeated outline of the letter V on the face of the bank, are cheap and efficient as surface-drains. On high banks these channels are sometimes needed, intersecting each other. Semi-cylindrical drain tiles, without holes, form a more perfect conveyance for the water.

In cases where a deep cutting occurs over a sharp curve, it is advisable to pare down the surface of the bank on the interior side of the curve. By this means the traffic is conducted with greater safety, as the view of the engine-drivers is much extended; and also the bank so flattened down is made more stable than it would otherwise be, such projecting points being peculiarly exposed to the weather, as similar points of a river-shore are to the tides.

The inner slope of embankments on curves may be advantageously filled in beyond the regular line, as the swelling of the mass after frost is thus allowed greater room, and there is less liability of the particles to ride over each other, which immediately occasions a rupture of the mass.

As the earth-works of a railway absorb a very large proportion of the total cost, it is evident that economy in this department is especially desirable. This depends mainly upon the nature of the material to be operated upon, and, to no inconsiderable extent, upon the season during which the work is carried on. Besides these influential circumstances, there are others, however, connected with the *manner* in which the operations are conducted, which will claim the anxious supervision of the engineer, and his duties in this respect are not much lightened by the work being usually committed to the contractors; for he has still to judge of their mode of proceeding, to estimate their future progress, to dictate measures for expediting, if necessary, and even occasionally to undertake the direction of every detail. It is therefore advisable to place before our readers a general account of the construction as usually carried on. The Plates I. III. IV. V. VI. and IX. will serve to illustrate this account.

On the method of conducting Earth-works. First; *Excavating.*—In starting an excavation through a hill of considerable height, it is desirable to get a fair face to the work, that is, one at right angles with the direction of the cutting; and from this face to start a system of gulleting or notching, by which labour is much economized. Fig. 1, Plate III., shows vertical niches cut in the face: a very little labour enables the excavator to separate the entire masses between these niches. The niches are not required much wider than may be made by the width of the pickaxe: a little undermining much assists the "getting." The consecutive operations required for an excavation are sketched in the figures on Plate IV. The cutting is supposed to have been commenced at the left end, and to have been started in the manner shown at fig. 1, Plate III. As the work proceeds into the hill, and the width is increased to provide for the slopes, it becomes desirable to run a "gullet" along the centre of the cutting, in order to bring the greatest number of waggons into use. Thus the temporary rails being laid in the gullet, a train of waggons is sent forward; these receive all the produce of the barrowing on either side, which is advantageously prosecuted in advance and alongside of the waggon-filling, for the purpose of keeping the work level for starting the next stage or layer of excavation. The sides of the gullet are shown as being notched, preparatory to widening it eventually to the full width of the cutting. As the height of the hill increases, the second layer is commenced, and side tracks are laid, inclining down on each side of the lower level. On these lines the full waggons

descend on one side, and the empty ones ascend on the other. The lines may lead into three branches, one along the centre of the upper gullet, and one on each side of it, to receive the side-barrowing and carry onward the widened gullet. Horses are required for moving the filled waggons to the head of the incline, (down which they are allowed to descend by gravity, and under command of the brakes,) and to draw the empty waggons up the incline on the other side. One of the great difficulties to be guarded against in excavating, is the accumulation of water in the lower parts of the cutting. To obviate this, the bed of the cutting should always be kept inclined upwards, as shown at fig. 2, Plate III., where the dotted line represents the permanent level to be attained, and the full line, that of the work while proceeding. By this means the water may be conducted to the end of the excavation, and there discharged. The soil thus left in the bottom of the cutting may be removed after the slopes are completed and the side drains formed, without leading to inconvenience. This slight rise being preserved in all the layers, also assists the descent of the loaded waggons.

Where the "lead" is in both directions from the centre of the intended excavation,—that is, where it is required to send the material got out to each end of the hill, the series of operations here described will be simultaneously commenced at both ends, and the excavations meet in the middle. In these cases the drainage must be effected by giving the bed a rise from each end to the centre, as shown in fig. 3, Plate III. If it be required to level the bed of the cutting as the work proceeds, a drainage may be secured by giving the rise for a short distance in front of the face of the work, as shown at fig. 4, Plate III.

Second; *Embanking.*—The ordinary, and commonly considered, quickest mode of forming an embankment is by running out to the full depth required at once, as sketched in figs. 1 and 2, Plate V. The front end of the embankment where the formation is proceeding, called the "battery head," at the right side of the Plate, is shown as having four lines of railway. The two outer of these lines run parallel to each other to the back of the bank, whence the material to be "tipped" over the battery head is brought. The two inner tracks bend outwards, and each flows into that one of the two parallel tracks which is nearest. A double crossing, as it is called, leads from each of these tracks into the other at some distance behind the tipping-place. It will be

seen on the plan that a range of full waggons, supposed to be approaching the tipping-place, is opposite to a range of empty ones, supposed to be returning for fresh loads. The order of proceeding is this: the four waggons, A, B, C, D, now occupying the head, being emptied, are returned in their alphabetical succession, as indicated by the relative positions of the four empty waggons lettered A^0, B^0, C^0, D^0, respectively. Meantime, eight filled waggons are approaching the point of activity, lettered on the Plate, A^1, B^1, A^2, B^2, and C^1, C^2, D^1, D^2. A^1 runs direct to the point just vacated by A; B^1, C^1, and D^1, each take corresponding positions at the battery head, returning in rapid succession as they are emptied, and being immediately replaced by those lettered A^2, B^2, C^2, and D^2. In this manner the two parallel tracks are always filled with full and with empty waggons, respectively, while four waggons are continually discharging their loads at the tipping-place.

One method of hastening the process of embanking is by keeping the top wider than intended eventually, and the base correspondingly narrower; an increased width for roads and tipping is thus obtained, and the extra width at the top is afterwards pared down to make good the deficiency at the lower part of the embankment.

Embanking may be carried on with equal, if not greater rapidity, by forming the bank at first to half the intended height, and following this closely with an upper tipping-place, just so much narrower than the lower one as will leave room for the waggons to pass down alongside to it. A sketch of this method is given in figs. 3 and 4, Plate I. The advantages of this mode are, that it gives a much wider tipping-place on the lower level, besides the upper one, and also, that during the time which the formation of the embankment precedes that of the top, the materials are becoming consolidated. Against these advantages must be placed the greater quantity of rails and plant required for conducting the work, and also that the subsequent completion of the upper layer, by a side slip, extending throughout the length of the embankment, prevents that thorough consolidation of the materials which is so desirable.

The most expensive course is that of forming the bank in shallow layers, running out each of them to the full length of the work, and following with the upper layers after each lower one is completed. By allowing each layer to settle (to the concave surface shown at fig. 2, Plate I.) before the next is formed, and, moreover, using beetles in ramming the earth down, an embankment will be formed of the greatest possible density and stability.

The method which combines economy with stability, in the best proportion, is by running forward the two sides of the embankment to the full width intended, leaving a central valley to be filled in at some little distance in the rear. The practical effect of this is, that the two sides become as narrow embankments, resisting the thrust of the central part afterwards put in; and alteration of form and position are much less likely to ensue with banks thus formed, than if they are carried forward with one battery head across the whole width of the work.

Both in embankments and excavations, the slopes should be dressed to the intended face, as shortly as possible after the formation is completed, and covered with turf, if possible, or at least with soil sown with grass-seed.

The implements, &c., constituting the plant, with which the earth-works of a railway are formed, consist, besides the minor tools—as picks, bars, shovels, &c.—of rails, chairs, sleepers, and waggons of various kinds. Frequently the rails used, which are very light, are of the longitudinal kind, that is, formed with a continuous bearing surface: with these rails the chairs are, of course, dispensed with, and longitudinal sleepers are employed instead of cross sleepers. In either case, the road, once laid down and put together, fulfils all its purposes with little attention or labour. If required to be shifted sideways or carried forward, a few bars are applied as levers by as many excavators, and the road is ready for work again in a very short time. As the amount of material removed will, to a considerable extent, depend upon the kind of waggons employed, a few examples have been collected from various authorities, and are represented on Plate IX. The figures on this Plate show three kinds of "end-waggons," those which discharge their load from the back or end; and one example of a "side-waggon," which is emptied over the side. Figs. 1 and 2 are an end and side view of an "end-waggon;" and figs. 3 and 4, end and side views of another; figs. 5 and 6, ditto; figs. 7 and 8, end and side views of a "side-waggon." Between the first two examples the principal difference is in the width and height. The details are also somewhat different, as will be seen on comparison. The narrower and higher waggon, shown in figs. 3 and 4, attains a larger angle when tilted, and this of course discharges its load more readily: on the other hand, the greater breadth in proportion to its length, of the first example, shown in figs. 1 and 2, gives that waggon a corresponding advantage. The broad waggon, however, leaving less space for the workmen

to pass, is attended with comparative danger, especially in cases where, for the sake of expedition, a great number of roads are laid down, and the intermediate spaces necessarily contracted. Figs. 5 and 6 represent a kind of waggon which was used on the Brandling Junction Railway, and is more readily emptied than either of the preceding. The body of this waggon, instead of turning upon a hinge, is supported upon two rollers. When the waggon is suddenly stopped at the tip, the momentum of the load carries the body forward, until its centre of gravity gets beyond the support, and the body is instantly, and, as it were, spontaneously tilted. The body is prevented from overrunning by a pair of curved metal stops, which are checked against the front rollers. The "side-waggon," shown in figs. 7 and 8, is supported upon two cross bearers, and hinged to them. It is adapted to tilt on one side only, and is necessarily somewhat higher than the end waggons are, in order to clear the wheels. All of these waggons are supposed to be fitted with brakes of a simple construction; merely a block of hard wood, shaped to fit a part of the peripheries of the two wheels, and capable of being turned upon a centre by a long handle of iron, which is carried to the front or hind end of the waggon, in order to be acted upon by the hand or foot of the brakesman. The handle moves within an iron slot, and may be pinned into any position by a pin passed through it. The form usually preferred for earth-waggons is nearly square, having a slight taper, or increase of width towards that end of the waggon which is turned downwards in the act of tipping: the under-framing, or "soles," should in all cases, as shown in the figures on Plate IX., project beyond the body, so as to leave room for the driver or others to escape to, in case of the sole-ends or buffers being forced violently together.

In some practical notes upon the subject of earth-waggons, published in the 'Civil Engineer and Architect's Journal,' (vol. vi. page 267,) under the signature of O. T., are the following:

"On the Midland Counties Railway, a waggon of a different construction to any of the preceding was used, both the sheaves and joints being dispensed with, the whole body of the waggon being lifted up from the hinder axle in the act of tipping, and the two axles being retained at an equal distance, so that the waggon falls to its original position as soon as the coup is recovered. I have seen wrought iron used for bodies of waggons of this construction, which answers a very good purpose. Several attempts have been made, but invariably without success, to combine the end and side-waggon in one construction, by

making the body of the waggon to revolve. Mr. Cuthbert Burnup made one so early as 1829, for the Newcastle and Carlisle Railway."

The best size for waggons is such that they will contain $2\frac{1}{2}$ cubic yards of earth. Wheels 3 feet diameter;—English elm is the best wood. About $3\frac{1}{2}$ cwt. of iron is usually employed in each waggon.

Figures 10, 11, and 12, Plate IX., exhibit a kind of waggon, which, if constructed of iron, as shown on the Plate, might be advantageously employed in delivering the material into a lighter or other vessel, if a stage be run out for that purpose. This waggon consists merely of a body, or receptacle, mounted on a frame of two side-arms, with stretchers between the wheels on each side. The larger wheels have a substantial axle; the small ones have none. The body, which, when filled, is nearly equipoised upon the larger axle, is suspended in front by two chains connected with the side-arms. The mere detachment of these chains admits the body to swing over and discharge its load instanter. The sketch shown in Plate IX. represents only the general appearance of such a waggon; the details are easily supplied. The original idea of such an apparatus was first, it is believed, carried out in a waggon or waggons used during the construction of the London Docks.

Figure 9, Plate IX., is an isometrical sketch of the "scoop" or "scraper," an implement which has been much used in America. From the account published in the American 'Franklin Journal,' in September, 1841, the following particulars are quoted:

"The scoop may be used with success in all excavations of earth where the slopes do not exceed $1\frac{1}{2}$ to 1, if the material to be taken out yields readily to the plough, and is not required to be moved horizontally more than 100 feet, nor to vertical heights exceeding 15 feet: there are, doubtless, instances where both these limits may be surpassed, and the use of the scoop still be highly economical; but such cases are not general, and the practical scope of the utility of scoops may be regarded as confined to the excavation of canal trunks, and the formation of low road embankments from side trenches, for both of which purposes it is most admirably adapted. This machine is drawn by two horses, managed by a boy, and usually requires the ground to be first ploughed; then, by simply elevating and guiding the handles a little, the driver causes it to load itself, for the horses being in motion, it turns its *clevisses*, and inclining downward, runs under the loose dirt like a plough: the handles

being released, the loaded scoop moves upon two iron-shod runners which form the sides and project below the bottom; and finally, after reaching the place of deposit, the handles being smartly elevated, the edge of the scoop, which is armed with iron, takes hold of the bank, and the horses moving on, it overturns and discharges its load: in this overturned position, with the handles resting on the double tree, it returns upside down to the place of excavation, and is there loaded, &c., as before."

Mr. Morris, from whose Report this account is quoted, proceeds to calculate the cost per cubic yard of excavating as performed with the scoop; and allowing 12*s.* 5½*d.* per day for the hire of the scoop (with the horses it is presumed), and the driver, and further, allowing ·54 pence per cubic yard for the preparatory loosening of the soil, he calculates the cost at 4·25 pence for "double scooping;" that is, working to both sides, and 5·5 pence for "side scooping." The difference between the two is, that for the former, the horses describe only a semicircle for each load put in bank; while for the latter, they have to make two turns or a complete circle.

Of late years the plough has been used in this country, and with great advantage, in the preparatory loosening of the surface for excavating. This method was, it is believed, first used in forming the London and Birmingham Railway. In that instance the material was a hard dry marl; and after a few experiments, which led to some alterations of the size and form of the plough for this particular purpose, the plan was found completely successful, and, moreover, it reduced the material in a much more perfect manner for the embanking, and actually dispensed with the labour of several men who were formerly employed to break up the lumps at the foot of the embankment.

Drainage.—In this important department of railway construction, the engineer is called upon to exercise the greatest care and precaution, and is, notwithstanding his most anxious exertions, very liable to find these insufficient for the preservation of his works. The history of all failures of earth-works shows the disasters consequent upon inadequate drainage; while in the majority of instances it must be, at the same time, admitted that no previous calculation could have foreseen, and scarcely any practicable arrangements have averted, the mischiefs produced by the hidden and insidious enemy—water. Wherever water is known or suspected to exist, its immediate source should be traced,

and every possible means adopted of diverting it from the slopes and adjacent surfaces.

Figures 6, 7, 8, 9, and 10, on Plate II., already described, show the ordinary kind of water-courses or ditches provided for excavations and embankments. Beneath embankments, every stream that is intersected, and every field-ditch or other natural or artificial water-way, will require a drain or culvert for the safe conveyance of the water away from the work; and these drains or culverts must, as well as all side ditches, be conducted finally into a river or stream of sufficient extent and activity to sustain the full discharge that can be required. The size of the culvert must of course depend on the quantity of water necessary to be provided for. The culverts must necessarily be built in before the embanking is commenced, and should, moreover, be allowed some weeks at least, to become consolidated before being covered in.

The figures on Plate VII. represent in detail a variety of culverts, &c., that have been adopted on various railways.

Fig. 1 is a cross section of an oval brick drain, 3 feet by 2 feet.

Fig. 2 is a section of a circular or barrel brick drain, 2 feet in diameter.

Fig. 3 is a section of the same, through the head and grating.

Figs. 4, 5, 6, and 7, represent a circular brick culvert of 3 feet in diameter: fig. 4 being a longitudinal section; fig. 5 a front elevation; fig. 6 a plan; and fig. 7 a cross section. The mouth of the culvert is formed with slopes, to correspond with the slope of the earth-work above.

Fig. 8 is a cross section of a simple kind of drain composed of stones, which, if large enough, may be laid dry, and yet answer the purpose of a water-way in some cases.

Figs. 9 and 10 are longitudinal section and front view of a circular brick culvert of 2 feet diameter. The face has a slight batter, and is built with footings, but without any expansion at the mouth, as in figs. 4, &c.

Fig. 11 is a section of a drain composed of rough pieces of stone, laid triangularly. Such a drain is frequently formed of chalk, and if carefully constructed, is very cheap and tolerably efficient.

Figs. 12, 13, 14, and 15, show a brick culvert of 4 feet diameter; the section of which is formed of four curves, of which the several radii are shown by dotted lines. This is a favourite and very strong section.

Figs. 16, 17, 18, and 19, exhibit the construction of an open drain, formed

simply of two walls of brick-work, the inner sides of which are battering. Two balks of timber, framed together, are laid across these walls, to carry a single line of rails.

Figs. 20, 21, 22, and 23, show a brick culvert of 8 feet width, adapted to discharge obliquely to its length, and constituting a "skew culvert." Fig. 22, the plan, shows the mode adopted of working the parallel lines of brick-work into the skewed face of the culvert; and fig. 23 is a cross section on the square, that is, at right angles with the direction of the culvert.

Fig. 24 shows the section of another oval brick culvert, the upper diameter of which is 2 feet 9 inches, and the lower 2 feet; the sides being right lines and tangents to these two curves. This section has been adopted and approved in some of the metropolitan sewers.

Figs. 25, 26, 27, and 28, represent another brick culvert of 6 feet diameter: the several radii of the curves of the section and the dimension of each part of the work are given.

Figs. 29, 30, 31, and 32, show a culvert of 4 feet diameter, formed with a circular head, a flat curved invert, and the sides with straight lines. It is composed partly of brick and partly of stone; the head and invert and springings being of brick, with stone footings and spandrils.

Figs. 33, 34, and 35, show a circular brick culvert of 2 feet in diameter, and may be described as exactly similar, but of different size, to figs. 9 and 10.

Figs. 36, 37, 38, and 39, show another circular brick culvert of 3 feet diameter, to which the description of figs. 4, 5, 6, and 7, will nearly apply. The face of this culvert is battered.

Figs. 40, 41, 42, and 43, represent a 5-feet brick and stone culvert, exactly similar to that shown in figs. 29 to 32.

Figs. 44, 45, 46, and 47, represent a 6-feet brick and stone culvert of similar construction.

Figs. 48 and 49 show a brick culvert of 10 feet diameter, similar in construction to those already referred to. Fig. 48 is a half elevation and half cross section, showing dimensions of the brick-work; and fig. 49 is a half plan.

Figs. 50 and 51 show a brick and stone culvert of 6 feet diameter, having a brick head-arch and invert, with stone blocking courses and backing. The front is formed with pilasters of ornamental character; against these abut stone walls, the top lines of which incline at an angle similar to that of the embank-

ment above. The courses are laid square with this line of inclination, and the walls are evidently well adapted for their purpose.

Fig. 52 is the cross section of a culvert of exactly similar construction, but of 8 feet diameter, and less height in proportion. The several dimensions for the brick and stone-work are given.

Figs. 53 and 54 are half elevation, half cross section and plan, of a 4-feet brick and stone culvert, with stone coping, blocking courses, &c.

Figs. 55, 56, and 57, show a double brick culvert with stone cut-water; each water-way being 6 feet in diameter, with circular heads, curved inverts, and straight-battering sides. The bed of the mouth is dished out slightly, to facilitate the discharge of the water.

Figs. 58 and 59 show a square drain, 1 ft. 6 in. wide, composed of stone blocks.

In cases where, from the costliness of land, or other causes, the sides of a cutting are upheld by retaining walls of brick or stone-work, the open side drains are usually abandoned, and a brick barrel-drain laid along the centre of the excavation, with cross drains dipping into it at intervals. By this arrangement the walls are drained without exposing the footings or incurring any additional depth of brick-work beyond that required for the stability of the walls. The drains here referred to are shown, together with the additional one required under two-arch bridges, on Plate VI. In order to keep the two archways dry, and avoid interfering with the foundations of the pier, the central drain is here branched into two courses. These receive two cross drains, situated one at each end of the bridge; other similar cross drains being, as already stated, repeated at intervals throughout the excavation.

Plate VIII. exhibits a paved double crossing of a line of railway on the same level; and also a metal single crossing, with the drains for the approaches, &c. Fig. 1 is a section, and fig. 2 a plan of the double crossing. Fig. 3 is a transverse section of the single crossing; and figs. 4, 5, 6, and 7, are details of the guard-plates enlarged. A further reference to this Plate will occur under the head "Permanent Way."

With a view to understand the assigned causes of, and applied remedies for, some of the slips and failures that have occurred upon railway earth-works, the following may be quoted:

In November, 1841, Mr. Brunel reported as follows:[29]

[29] Report of the Officers of the Railway Department, 1842, page 90.

"The Swindon embankment of the Cheltenham and Great Western Railway is about $1\frac{3}{4}$ miles in length, and averaging about 20 feet in height, nowhere exceeding 24 feet, and was formed originally of clay obtained from side-cutting. The embankment was made of full width, the slopes good, and a wide bank left between the foot of the bank and the side-cutting. In fact, in the setting out or designing of the work, I do not feel that any precaution was omitted, excepting so far as the formation of an embankment of clay by barrow-work under any but the most favourable circumstances may be considered injudicious. Certainly my subsequent experience in works under my own direction, and observation upon others, have convinced me that if an embankment so formed suffers more than any other from the effects of continued wet during its formation, or before it is consolidated, the loose and divided state in which the separate lumps are thrown together from the barrow, instead of being compressed by the fall from the waggon at the tip-head, easily accounts for this; besides the circumstance of the surface being generally unavoidably left in a much more irregular form, and less capable of being drained.

"Unfortunately, during the formation of a great portion of this embankment, the season was excessively wet. Several small slips occurred in the following year, and in repairing these slips the interior of the bank was found to be saturated with water, and in a soft, almost fluid, state. Still the means taken to remedy the slips appeared effectual. Large portions of the slopes of the embankment were burnt, and the masses of burnt clay thus formed, appeared capable of supporting the pressure of the soft clay within. Further precautions were subsequently taken: portions of the side-cutting, where the foundation of the embankment had given way, were filled up, and the embankment made good every where with good dry rubble and sand brought for that purpose. Every thing was done which I considered desirable to insure the permanence of the work. Immediately after the opening of the line, however, whether in consequence of the working, or from other causes, the bank again began to move, the slips being almost exclusively confined to the up or east side. It appeared most prudent to abandon the attempt of keeping up this line for the running of the trains, to bestow all the attention to the down line, and to use the other for the purpose of bringing materials for the maintenance and restoration of the embankment. The work has been proceeded with ever since as vigorously as the circumstances would admit; the whole of the soft material is being removed or forced out; the side-cuttings are being filled up; a dry

stone wall built at the foot of the slip; and the embankment almost re-formed of rubble." This wall is 12 feet thick, built at the bottom of the slope to the depth of 10 feet.

In January, 1842, Major-General Pasley reported upon the slip which occurred in that month upon the London and Croydon Railway, near New Cross, as follows:

"The original slope of the sides of the deep cutting where this slip took place was 2 of base to 1 of height, and they had stood for more than two years without any slip of such magnitude as to prevent the passage of the trains through this cutting until lately, when the continued rains have produced this unfavourable effect, which I do not think that any engineer could have anticipated beforehand, for it is only our late experience that has developed the disadvantages of deep cuttings and high embankments in certain kinds of clay, even at very moderate slopes. No blame, therefore, attaches to the original construction of this railway, though the extraordinary slips that have occurred recently will be a lesson to put engineers on their guard for the future in working in such soil. On the east side of the cutting the extreme height was rather more than 100 feet in one part, with 200 feet of slope."[30]

Sir Frederic Smith reported[31] in November, 1841, upon the Sheffield and Manchester Railway, thus: "In the centre, the Newton Green embankment is about 45 feet high; and whether from the nature of the materials, or the unfavourable state of the weather when formed, or the late heavy rains, it would be difficult to determine, but it has subsided to such an extent, that the base has spread out to two or three times its original width. Mr. Locke, observing that any additional materials of the same description only tended to increase the evil, used light sand to regain the required elevation in proportion as the embankment subsided; but finding that this attempt to obtain a steady surface has also proved unavailing, he has recently thrown two lines of large timbers, as longitudinal bearers, across the treacherous ground.—These timbers are 16 inches square, scarfed at their meetings, and the scarf is supported by a template. This again stands on an upright shore. Other shores are placed at intervals of 10 feet apart under the bearers, and the shores standing opposite to each other rest on a cross sleeper of about 16 by 9 inches."

[30] Report of the Officers of the Railway Department, page 92.

[31] Ibid. page 177.

The following figures, referring to the earth-works on some of the English railways, will conclude this Section.

Birmingham and Gloucester.—The earth-works amount to		76,250	cubic yards per mile.
Chester and Birkenhead	Do. . . .	82,451	,,
Great North of England	Do. . . .	32,000	,,
Lancaster and Preston	Do. . . .	100,000	,,
Liverpool and Manchester . . .	Do. . . .	90,000	,,
London and Brighton	Do. . . .	156,000	,,
London and South Western . .	Do. . . .	143,434	,,
Manchester and Leeds	Do. . . .	100,500	,,
London and Birmingham . . .	Do. . . .	142,000	,,
Midland Counties	Do. . . .	94,112	,,
North Midland	Do. . . .	131,034	,,
North Union	Do. . . .	116,120	,,
Sheffield and Rotherham	Do. . . .	76,000	,,
Stockton and Hartlepool . . .	Do. . . .	41,000	,,

SECTION III.

RETAINING WALLS, BRIDGES, TUNNELS, &c.

Considered in its applications to railway service, the art of bridge building appears at once to demand and to be susceptible of being reduced to a system of proportions and strengths, combining all the solidity and durability that may be required with the utmost practical economy in cost. In preserving the essential conditions of the line, the number of bridges and other similar structures is necessarily much greater than would suffice for the same length of common road whose gradients and windings might range within much wider limits than those prescribed for locomotive transit. For every mile of railway hitherto constructed in Great Britain, from two to four bridges have been built; and many of these, it must be remembered, are not mere single-arch structures, but viaducts of hundreds of feet in length, of great height, and consequently great solidity and cost. It is evident therefore that a single item of defective design in these works entails most severe losses, either from excess of first cost on the one hand, or from expensive repairs and additions on the other; and, together with this occasion for scrupulous care and exactness in designing and executing these works, those which carry the railway appear to admit of calculations of the load they will be required to support, much more readily and exactly than ordinary road bridges, the load upon which is liable to all sorts of fluctuations.

This subject has of course occupied the careful attention of railway engineers, and the experience already obtained has produced many splendid examples, which unite sufficiency and economy in a high degree. Nevertheless, the former of these conditions is so much more readily seen and appreciated than the latter, that the "let-well-alone" theory cannot be trusted, and every

one who receives the charge of railway works should feel himself stimulated to a thorough consideration of this subject.

Before directing the reader's attention to the several examples of bridges which have been collected for this work, I would beg, first, to recount the more prominent points for consideration in designing such structures; and secondly, to present a simple classification of the several varieties under which they may be arranged, according to the circumstances of each case. It would, of course, be equally beyond the pretensions of this descriptive sketch, and supererogatory as dedicated to the use of the Corps of Royal Engineers, to attempt any exposition of the theory of bridge building; but a brief outline of the several points of practical importance will, it is presumed, serve to facilitate the arrangements of the engineer, and may save the trouble of further reference. According to the order adopted at the head of this Section, we have first to regard

Retaining Walls.—The only cases in which artificial retaining walls appear desirable are those in which it is actually or nearly impossible to interfere with the surface, which would otherwise be required, in order to substitute cutting or embankment at the natural slope of the material of which they may be composed. Many instances are recorded of the failure of these structures, which has commonly resulted from the saturation and consequent swelling of the earth behind them; and these effects have occurred frequently, despite the most judiciously selected forms and materials, and the best attainable system of back drainage. Indeed, unless the material be adapted to stand by itself, be thoroughly impervious to water, or so completely drained that very little reaches the back of the wall, it is certain that this uncontrollable agent will make its way through the work, and produce sooner or later the disastrous consequences which have already marred the designs of railway engineers.

As applicable to cuttings, artificial retaining walls, unless they can be constructed under most favourable circumstances, are best secured by arches thrown between them, or by other intermediate resistances, which are required to act as abutments between the two walls, and prevent their forward movement towards each other. With this addition, it is evident that the structure becomes a bridge, or nearly assimilates to one, and is palpably inapplicable to very long walls, except at a tremendous cost.

As applied to the feet of embankments, where the material is of that cohesive

but slippery nature that a simultaneous movement of the entire mass may be apprehended, low and strong retaining walls are useful, and present frequently a judicious expedient, although in many cases less advisable than piling or wattling. As protections against the sea, retaining walls to cover the lower or entire face of the embankment afford the best means, although frequently very expensive, of securing the stability of the work; but in all such and other cases, if any thing more than a mere breakwater or rude collection of heavy stones, the wall, sloping back to the embankment, becomes rather a facing of masonry than an independent construction, and contributes to the stability of the work only by its artificial cohesiveness and greater weight. Applied to the entire height of embankments formed to a steeper slope than that at which they would stand independently, retaining walls may be considered never advisable, and would be infinitely better abandoned for a cheap construction of viaduct.

When their adoption, however, becomes imperative, the stability of retaining walls will depend upon the nature of the soil behind them, and the means taken for its drainage; and upon the form of wall adopted, and the manner and materials of its construction.

The amount and kind of pressure of the earth against the wall which retains it are evidently affected by the angle of repose, or natural slope of the earth; also by the quantity of moisture it will imbibe, the proportion of this which it will retain, the extent to which its absorption of water will cause expansion of the mass, and by other circumstances.

The natural slopes of some kinds of earth have been observed experimentally, and are thus recorded.

1. Fine dry sand	35° 30′
2. Gravel (dry?)	37°
3. Loose shingle, perfectly dry	39°
4. Common earth, pulverized and dry	46° 50′
5. Ditto, slightly damp	54°
6. Earth, the most dense and compact	55°

Of these results, No. 1 is the mean of experiments recorded by Rondelet, Barlow, and Hope;[1] No. 2 is on the authority of Lieut. Hope; No. 3 is recorded by General Pasley; Nos. 4 and 5 by Rondelet; and No. 6 by Barlow.

According to the specific gravity of these substances, it appears that the

[1] 'On the Pressure of Earth against Revetments,' by the late Lieut. Hope. Professional Papers of the Corps of Royal Engineers, vol. vii. art. xi.

weight of the triangular section (one foot thick), which is bounded by the vertical back of a wall 10 feet high, a horizontal line level with the top of it, and the natural slope of the material, will be about as follows:

1. Sand	6800 lbs.
2. Gravel	6350
3. Shingle	8600
4. Earth, dry	4800
5. Ditto, damp	3700
6. Ditto, dense	3580

The mere weight of earth to be sustained thus appears to vary very widely according to its constitution and state of dryness or moisture; but this comparison of weights, forming only one element of the calculation, does not furnish any estimate of the actual resistance which the wall is required to exert. This will evidently be reduced by the cohesion of the moving mass, and by the friction between this mass and the natural slope of that portion which would remain stationary in the absence of the wall; but, on the other hand, it is increased in a great degree by the action of water within not only this moving mass, but also the otherwise quiescent mass beneath it.

In a state of perfect dryness, and disregarding the withholding effect of cohesion and friction, the maximum power required in the wall would be represented by the actual weight of the retained earth, supposing this weight to act against the vertical plane of the wall with the same force that it would exert upon a horizontal plane that supported it. And the power thus required in the wall might be immediately calculated for each section of its altitude; but the moment that water is introduced within the retained material, a multitude of other considerations arise, which no theory has yet furnished the means of estimating, and which require a series of experiments to enable us to predetermine with any chance of accuracy.

Upon the methods of draining retaining walls, reference may be made to the account of the Blisworth cutting, given in the second Section of this Paper;[2] also to the description of the mode of repairing the walls of the London and Birmingham Railway, contained in the seventh volume of the Professional Papers of the Corps of Royal Engineers.[3]

Among the various considerations to be entertained in the designing of retaining walls, that of the influence of *season* should not be disregarded. A wall built during a dry season, or after a long drought, will incur an augmented

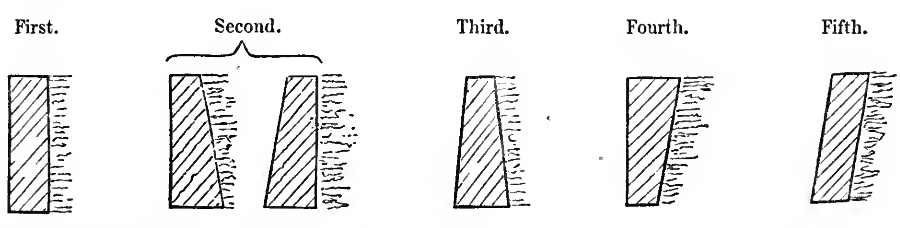
[2] Description of Plate II.

[3] Art. xv. page 160.

pressure when the earth becomes saturated with water; and on the other hand, if built during a wet season, and backed up with wet earth, it will be subject to a shrinking away of this backing when subsequently drained. The engineer can provide against injury from these circumstances only by making the wall as far as possible self-supporting, so that any retiring of the earth behind shall not endanger its stability; and at the same time, offering every facility for the water to find its way through the wall, and for discharging it thence into the foundation drains. The most perfect wall would be that which should be throughout its whole surface completely permeable by water, so that no accumulation of that fluid could occur behind it, and which should yet effectually retain the particles of earth. Upon such a wall the effect of the earth would be reduced into that of its mere weight, and experiments would be needed only to determine the best arrangement of bricks and mortar, or other materials, for resisting this action.

As to the best and most economical *forms* for these walls, we are enabled to describe some which have been constructed, and have fulfilled the purpose of their construction, and we may also refer to the objections against some forms which have been suggested and adopted; but on this part of the subject experiments are also much wanted, and under this conviction, all must regret the premature loss of Lieut. Hope, whose skilful labours in this department promised so many valuable results to civil as well as to military engineering.

Of plane walls, five different forms have been constructed: first, having vertical faces; second, having one vertical and one inclined face, converging towards the top, and presenting either of these surfaces to the retained earth; third, having both faces inclined, and converging towards the top; fourth, having one vertical face, the other inclined and converging towards the bottom; fifth, having its faces inclined and parallel.



Each of these forms is sometimes varied, by curving the inclined lines: then, the second form will present a concave surface to the retained material, or otherwise a concave exterior surface; the third will have a concave surface

towards the earth, and either a concave or a plane inclined exterior surface; the fourth form will have a convex surface against the earth, and a plane vertical surface externally; and the fifth form will present a convex surface to the earth, and a concentric concave surface externally.

Of these forms, the first three are evidently adapted to stand alone; while the fourth and fifth will depend for their stability partly upon the outward thrust which the retained material will exert against them.

It is frequently found that the middle or upper part of a retaining wall fails first, and will be thrust some inches forward, while the lower part of the wall remains firm. This occurrence, which, considering the greater weight opposed to the lower part of the wall, cannot be attributed to the mere weight of the earth, is probably owing partly to the superior strata being less dense, and therefore more rapidly saturated with water than the lower strata. This would lead to the necessity of providing especially for the complete surface drainage of the retained district.

In other instances of defect, the whole wall is moved bodily forward, and sometimes with very little fracture. This was the case with a portion of the wall built on the line of the Birmingham, Bristol, and Thames Junction Railway, which for a length of 40 or 50 yards was pushed forward off the foundation, to a distance of 8 or 10 feet, the wall still standing. This failure was pronounced by Mr. Vignoles, who examined the works at the time, to have resulted from the accumulation of water, which, "having no outlet, had settled the earth against the back of the retaining wall, turning the clay into mud, and by the great additional weight forcing it into the position in which it then appeared."[4]

There is no doubt that the ultimate stability of retaining walls is affected by the state of dryness of the masonry when the earth is filled in behind it; and also by the manner in which this filling in is conducted.

Upon the latter subject some valuable remarks were made by Mr. J. B. Hartley, in a Paper read before the Institution of Civil Engineers, in the session of 1841. From an abstract of that Paper, published in the C. E. and A. Journal, (vol. iv. p. 395,) the following may be usefully quoted.

"The author considers the method of filling *towards* the wall from the natural bank to be highly objectionable; the material lies in strata at the angle at which the deposit is made; as the quantity increases, the subsidence com-

[4] 'Civil Engineer and Architect's Journal,' vol. v. page 95.

mences, and the earth slides downwards, throwing its whole weight against the back of the wall. The tendency to slide is frequently accelerated by the natural form of the ground upon which the earth is thrown, as it not unfrequently inclines towards the wall, in which case the pressure will necessarily be in proportion to the inclination of the slope, and the nature of the material of which the filling is composed. The wall at Hunt's Bank, on the river Irwell, is instanced as a failure of this description. The wall, about 100 feet in length, and 20 feet in height, 5 feet thick at the bottom, and 3 feet 6 inches at the top, built of ashlar masonry, strengthened by counterforts, was forced into the stream by the pressure of the earth behind it. With proper attention to the manner of filling in the different materials, a comparatively slight wall may be constructed to sustain a considerable weight of backing. The author lays down as a rule, that wherever it is practicable, all filling behind walls should be *commenced at the wall*, and be proceeded with from thence towards the solid ground, by which means the strata would be inclined in a similar direction: ledges or benches, either level or inclined in an opposite direction to that of the bank, should be cut in the solid ground to receive the filling, and counteract its tendency to slide. The weight should not be laid too quickly upon a new wall; and if with these precautions care be taken that the counterforts are constructed simultaneously with, and well tied into, the wall, a comparatively weak structure will bear a heavy mass of filling.

"The author gives as an example the retaining wall constructed on the west side of Jackson's Dam, near the Brunswick Graving Docks, Liverpool. This wall, although built of slight dimensions, and filled behind with material of the worst description, resisted perfectly all strain: this could only be attributed to the filling having been gradually done in the manner which the author's practice leads him so strongly to recommend."

Reverting to the *forms* for retaining walls, it may be remarked that a preference has been shown towards the fifth, with some little modification. By railway engineers this form is usually reduced in thickness at the top, by steps on the inner face. The experiments made at Dublin, under the direction of Sir J. Burgoyne and the Board of Public Works of Ireland, are quoted by Mr. Vignoles as fully proving that the "parallel battering-wall" is the one which offers the most support, with the least quantity of material. And one of the results deducible from the experiments instituted by the late Lieut. Hope, at Chatham, is in favour of the "leaning wall with counterforts." Lieut. Hope

"conceived that the face of the revetment might be a mere shell, hardly exposed to any pressure, the earth being chiefly supported by its friction against the sides of thin but frequent counterforts."[5]

These results cannot however be admitted as conclusive against the several other forms which have been, in some instances, adopted. Thus the second form appears well adapted for stability, and has the advantage of an enlarged section below, and a reduced one above, from the same amount of materials as No. 5. Again, the third form appears to be very strong, and well adapted to escape injury from any extra pressure resulting from the absorption of water by the retained bank.

But it must be observed of the first, second, and third sections, that the inner face of all of them departs more widely from the natural slope of the earth, and therefore sustains a greater pressure than the inner face of section No. 5. Section No. 1 is evidently inferior, by reason of its uniform thickness, which must be either excessive at the upper, or deficient at the lower, part of the wall. This defect of uniform thickness is partly compensated in No. 5 by its inclined position, which gives it a tendency to fall back upon the earth, and thus resist its pressure.

The value of this fifth form of retaining wall appears to arise from the line of direction being thrown beyond the centre of the base, thus giving a preponderating weight within this line, the effect of which weight increases in proportion to the height of the wall and its divergence from the perpendicular. The angle of this divergence remaining the same, the height may be supposed to be reduced till the line of direction falls within the base, and the active weight of the wall becomes reduced to nothing; or, on the other hand, the height may be supposed to be increased until this active weight shall equal any pressure of the retained earth. And this consideration will perhaps partly account for some of those instances of movement in the *middle* or *upper part* of retaining walls thus formed, which are well known in practice, and which we have already had occasion to notice. In these cases we may imagine, that unless the construction of the wall is such as to insure a superior cohesion among its parts, the upper part of the wall will have a tendency to fall backward, while the lower part (of which the line of direction falls within its base) will have no such tendency. The upper part, obeying this tendency, becomes dislocated from the lower, and will be forced forward by the pressure behind it.

[5] Professional Papers of the Corps of Royal Engineers, vol. vii. p. 86.

The great importance, in works of this class, of judicious construction, not only in design, but also in practical execution, will justify the introduction of a few hints upon brick-work and bonding generally, especially as in all considerations upon those works we have to assume the perfect cohesion and entire rigidity of their parts; and our conclusions will, therefore, be the more fallacious in proportion as these conditions are neglected and non-realized in practice.

In the first place, the arrangement of the bricks should be that known as *English* bond; viz., one course of headers and one of stretchers alternately. The bonding of the plain part of the wall should be secured by introducing a half brick for every alternate outside header on both sides of the wall, so as to connect the outside headers with the bricks in the interior of the same course. At every fourth course, or thereabouts, three or four bands of iron hooping, laid parallel, and bedded in the joints, assist the bond. At each returning wall or counterfort, quarter bricks are required, in order to avoid straight joints on the face of the wall, and preserve the bonding at these angles. In all battering walls it is especially necessary to insist upon narrow joints perfectly filled with mortar, and truly pointed. This is the only means of guarding against, or rather deferring, that penetration by wet and frost which is so detrimental to the stability of the work. The bricks, too, should be thoroughly wetted before and during the setting, so as to detect any injurious quantity of limestone which may exist within them, and also to cleanse them and render the mortar thoroughly adhesive. In all cases the work should be brought forward simultaneously, or as nearly so as possible, throughout the whole length in hand, otherwise the shrinkage which invariably occurs will be unequal, and produce internal dislocations of the wall, which will accelerate, if not produce, ultimate failure. Similarly, all counterforts must be erected along with the wall itself, for all subsequent connections of these parts will be necessarily imperfect.

The concrete and lower courses of brick-work or footings should be deeply notched into the solid ground on the inner side of the wall. If this be carefully observed, and all spaces in the excavation or trench cut for putting in the foundations be well rammed, no movement of the foundation can take place without it be actually lifted to the extent of its entire depth, or without crushing the solid ground before it. In a similar manner, all the courses of brick-work should have a dip downwards from the outside face of the wall, and, in short, every possible means be adopted of connecting the entire mass of wall and foundations indissolubly together.

All reductions in thickness should be made in steps, keeping the intermediate sections of the wall parallel; for if any attempt be made to reduce by tapering lines, the restriction to proper sized bricks and parts of bricks is necessarily disregarded: bats, and pieces of every variety, size, and shape, are thrust in, so as to preserve the outside lines only; and good bonding and narrow joints are alike unheeded. And this forms a great practical superiority of the fifth form of wall over the second, third, and fourth. The fourth section, indeed, is otherwise so objectionable, that it can be selected only under the absolute necessity of preserving a vertical face, and a back inclined towards the natural slope of the retained earth.

A practical rule for a section of retaining wall which has in many cases proved sufficient, and has yet been deemed economical, is as follows:—let the batter equal one-sixth of the vertical height of the wall; the thickness of wall at the bottom equal one-fifth of this height, and the thickness at top one-tenth the height, or one-half the thickness at bottom: and for the reducing of the thickness, divide the entire height into as many equal parts, plus one, as there are half bricks in the difference between top and bottom thickness. Thus a wall 30 feet high will batter 5 feet, be 6 feet thick at bottom, 3 feet at top, and be divided into nine different thicknesses, each $4\frac{1}{2}$ inches less than the lower adjoining one, and each 3 feet 4 inches in height, measured vertically.* Under ordinary circumstances, however, economy of material may perhaps be effected, or greater stability be secured, by reducing this thickness, and introducing small counterforts at frequent intervals.

BRIDGES, AND VIADUCTS.

During the development of the railway system in Britain, the economy of bridge building has necessarily received much attention, and has been illustrated by a multitude of structures, exhibiting many varieties of design and of material. That this vast experience has led to substantial improvements and to saving in cost, may be inferred from the fact, that in many cases bridges and viaducts of great extent are now adopted in preference to mere

* This wall appears very light: a mean thickness of one-fifth of the height, or 6 feet, would be the minimum I should like to trust; and this would give the base 9 feet wide instead of 6 feet.—W. D., Editor of the Professional Papers.

earth-works,—a long viaduct being now available at less cost, original and current, than an embankment of similar extent; whereas, in the early experience of railway making, it is well remembered that the most expensive earth-work was almost invariably adopted, both for economy and ultimate sufficiency, in preference to any description, then approved, of bridge-work.

In this sketch it is presumed that bridges and viaducts may be treated under the one common head,—bridges,—and with no attempt to distinguish between them, the one being deemed only a more extended form of the other.

The several cases in which bridges are required in railway works, and which may be judiciously treated with difference of design, of dimensions, and of materials, are intended to be indicated by the eight figures in Plate X. These are arranged in two classes, headed A and B; the one including bridges *under* the railway; the other, bridges *over* the railway. Each class comprehends four cases, viz.: First, where the levels of railway and of common road crossing are originally coincident. Second, where they differ just so much as will suffice for headway under the arch. Third, where they differ to any great extent beyond the required headway; and, Fourth, where they differ less than the required height.

In the eight figures on Plate X., it should be observed that L.R. signify *level of rails;* O. S., *original surface;* and A. S., *altered surface.*

In the first case, the required crossing may be obtained either by cutting deep enough to get height for the common road traffic below the railway, and cutting inclined approaches, thus lowering the road level; or it may be obtained by elevating the road level, throwing a bridge over the line, and making embanked approaches to the summit of the bridge. If the selection between these be within the engineer's power, several considerations will occur. As regards earth-work, the one design will *produce* nearly the same quantity of material that the other will *consume;* the one or the other will therefore be desirable, according as there may be a deficiency or excess of earth in the adjoining parts of the line. In economy of brick-work, the bridge in cutting has the advantage, as the footings require to be sunk only 18 inches or 2 feet below the slope; while the bridge in bank (as shown at B, fig. 1) will require the abutments so much below the original surface. The latter will also require fences on the approaches, which the former will not. On the other hand, the bridge in cutting will involve more expense in drainage than the bridge in bank; and this consideration must be entertained with full regard to the com-

parative levels of the surrounding districts, and will frequently be found to outweigh all the other advantages of the sunk bridge. In either bridge, wing walls may be well dispensed with; the abutments should be allowed to cut into the bank or the slope, and be lightened as much as possible by side arches and by arched openings, with inverts in the cross section.

In the second case, the road crossing is supposed to be required at a point where the railway is either in an embankment of about 16 feet high, or a cutting of about 16 feet deep. In either instance, the best structure will be obtained by adopting a bridge with parapets parallel throughout, or very slightly diverging from each other at each end; by making it sufficiently long to allow easy slopes for the banks, an ample width of road, and for the abutments to cut well into the slopes on each side; thus dispensing altogether with wing or retaining walls, which are always expensive, and seldom secure.

In the third case, where the difference of levels is very considerable, and an extended structure or viaduct is required, economy of construction becomes additionally important. A reduced width of viaduct, so as to provide for one line of rails only, has been sometimes recommended; but this is a kind of economy which can be justified only under peculiar circumstances, and which may be productive not only of much inconvenience and hindrance, but of greater ultimate expense than the double width would at first involve.

For structures of this magnitude, the sufficiency of foundation is of the first importance: the greater altitude not only imposes greater weight of materials to be supported, but also evidently requires that the cohesion of the foundations, and indeed of the whole structure, be more perfect, as any defect or dislocation is more likely to occasion extensive mischief in proportion as the height is increased. If gravel or chalk can be reached, with a good bed of concrete nothing need be apprehended; but if loam, sand, or bog occurs, piling is found the better expedient. Upon a good foundation, piers and arches may be constructed of a light, yet sufficient and economical character. The late use of timber for works of this class has much reduced their cost; but experience has not yet been had which would warrant the assertion, that the expense of current repairs may not, in some instances, outweigh the economy in first cost. The prominent advantages of timber for works of this class, as applied in the timber-arched bridges, are,—the large spans which may be adopted, thus reducing the number of piers required,—the comparative lightness of the whole structure,—and the facility and rapidity of erection. Much less scaffolding is needed in

building these timber bridges than in building those of masonry; less time is required for the consolidation of the materials; and in most districts, timber, and workmen for fashioning it, are so much more readily and cheaply procurable than stone or bricks, and masons, that some overwhelming objection must be proved in order to justify the abandonment of the former material. This objection has been foreseen by some persons in the anticipated rapidity of decay of some of the parts of timber bridges, and in the difficulty of replacing such parts, and effecting the necessary repairs.

In the district between Newcastle and North Shields, two viaducts have been constructed of timber by the Messrs. Green, the total cost of which was about £48,000; and it has been estimated that the saving effected by using timber instead of stone amounted to £14,000. In one of these viaducts, that over the Ouse Burn, Mr. B. Green states the amount saved was £9000. Mr. Mitchell, who about sixteen years ago erected a timber bridge over the Spey, having one arch of 100 feet span; and subsequently another having two arches of 100 feet span each, with stone abutments and piers; and a third across the Dee, of five arches of 75 feet span each, with timber piers,—states that timber bridges are one-third less expensive than those of masonry; and if built with timber piers, as in that one over the Dee, the saving amounts to one-half. Mr. Mitchell further states the period of their duration to be from 30 to 40 years, but does not furnish data for estimating expense of current repairs. Mr. Vignoles compares the Ribble viaduct, on the North Union Railway, with a timber viaduct. The former, he states, cost £60 per lineal foot, while the latter would cost only £20 per lineal foot; the Ribble viaduct being only 50 feet high, with five arches of 120 feet span, and the timber viaduct 100 feet high, with arches of 130 feet span, the width of roadway in both cases being 28 feet. These comparisons of cost depend, however, so much on the relative facilities for procuring and working each material respectively, that no general estimate can be offered of the advantage to be gained in this respect by the adoption of either.

The particular construction of timber bridge referred to already as having been applied upon the Newcastle and North Shields Railway, was described by Mr. B. Green, in a Paper read before the Institution of Civil Engineers, in March, 1841. Two viaducts have been mentioned, built by the Messrs. Green, described severally as the "Ouse Burn" and the "Willington Dean." Mr. Green's Paper referred particularly to the former viaduct: Plate XVII. exhibits in detail the construction of the arches and piers of the latter, but as both

viaducts are exactly similar, with only trifling differences of dimensions, the following abstract of Mr. Green's description will be equally illustrated by the same Plate.

"Mr. John Green, in the year 1827, made a design and model for a bridge, with timber arches resting upon stone piers. In 1833 the plan was adopted, and in 1837 it was put into execution at the Ouse Burn viaduct, where the construction was of great extent, and the cost was an important consideration. The viaduct is 918 feet in length, and 108 feet in height from the bed of the river. There are five arches, the versed sine 33 feet, and the radius 68 feet; three of them are 116 feet span each, and two are 114 feet each: two stone arches, of 40 feet span each, have been introduced at each end, to give length to the abutments, and to prevent the embankments from being brought too near to the steep sides of the ravine. The piers are of stone: the springing stones for the three ribs, of which each arch is composed, are on offsets, within 40 feet of the top of the piers; cast iron sockets are there bedded in the masonry, and secured so as to receive the feet of the ribs. Two of the piers are placed upon piles; the others are founded upon the rock: immediately beneath the centre of one of them an old coal-pit shaft was discovered, and close adjoining to it the remains of the working of a coal seam: both were rendered secure by being filled up with grouted rubble masonry. The ribs for the arches are composed of planks of Dantzic deal (Kyanized): the lengths vary from 46 feet to 20 feet, by 11 inches wide and 3 inches thick: they are so disposed, as that the first course of the rib is two whole deals in width, the next is one whole and two half deals, crossing the joints longitudinally as well as in the depth. Each rib consists of fourteen deals in thickness, bent over a centre to the required form, and secured together by oak trenails, $1\frac{1}{2}$ inch in diameter, at intervals of 4 feet apart, each trenail traversing three of the deals. A layer of strong brown paper, dipped in boiling tar, is placed between the joints, to bed them and exclude the wet. Trussed framings and beams are secured upon the arched ribs; the platform, composed of planks, each 11 inches wide by 3 inches thick, is spiked down and covered with a composition of boiling tar and lime, mixed with gravel in laying on, forming a coating impervious to the wet: upon this platform the two lines of railway are laid, leaving a footpath between them. The centering for turning the ribs was very light and simple, and as every convenience was afforded by having a railway with travelling cranes along the sides of the piers, a whole centre could be moved by twenty

men from one arch, and fixed in another, in one day." In a conversation which followed the reading of this Paper, Mr. Rendel remarked, that from experience he could not recommend either paper or felt between the joints, as therein described. "He found that both substances prevented the intimate contact of the surfaces of the timber; in all framings exposed to the action of the weather, the tar was absorbed by the wood; the paper and felt then became saturated with and retained the moisture, so that decay very speedily ensued. The mode he at present adopted was to have all the joints and mortises of the framings very closely fitted, leaving only sufficient space at the edges to be caulked with oakum, and the joint run with pitch, like the seams of the deck of a vessel. Wherever it was practicable, great advantage would result from covering the joints with sheet lead, to exclude the moisture and prevent the decay, which was the great bar to the more general use of timber in many engineering works." And Mr. Macneill stated that he "had found constant trouble to result from the decay of wooden bridges. The Dalmarnock bridge, which had been erected about thirty years, now demanded continual repairs; the struts were nearly all decayed at the point of insertion into the cast iron sockets. The original floor had been replaced by one of teak wood."[6]

As the building of the bridge here instanced by Mr. Macneill was anterior to the use of the wood-preserving processes now adopted, it may be questioned how far any of these processes might have arrested the course of decay. It may perhaps be also considered whether their contact with the cast iron sockets may have affected the soundness of the struts, and if so, in what degree.

Although a detailed examination of the several methods which have been latterly adopted for the preservation of timber would be out of place here, yet a condensed notice of some of them, and of the observations recorded upon their results, seems necessary in order to point to the evidence on which the extensive use of this material in railway viaducts and bridges is desirable or otherwise. The great economy, in first cost, of preferring timber to masonry both for long viaducts of small elevation, and for shorter ones of great height, is so far an established fact, that in all cases where this kind of economy is imperative, no discretion will be permitted in the choice of material, and the

[6] Report in 'Civil Engineer and Architect's Journal,' vol. iv. p. 284.

greater question—can wood be so far preserved as to make its employment desirable with a view to ultimate economy?—will be cast aside for the minor one—how can wood be the best preserved? But whichsoever of these questions has to be considered, the subjoined evidence will, it is believed, be equally useful.

The four processes which have been most prominently brought before the notice of the profession, are those known as Kyan's, Burnett's, Bethell's, and Payne's.

Kyan's process, secured by patent, March 31st, 1832, for preserving wood, consists in immersing it in corrosive sublimate or bichloride of mercury, until the wood becomes as far as possible saturated. In the year 1705, M. Homberg stated, before the Royal Academy of Sciences at Paris, that "a person of quality in Provence, not knowing how to preserve inlaid work, from the worms destroying it in a few years, as it frequently happens in that country, he had advised him to steep his inlaid work in water wherein corrosive sublimate had been mixed, which succeeded very well."[7]

"In the valuable work upon the dry-rot, published by Mr. Knowles, Secretary of the Committee of Inspectors of the Navy in 1821, corrosive sublimate is enumerated among the chemical substances which had been prescribed for preventing the dry-rot in timber; and it is well known that Sir H. Davy had, several years before that date, used and recommended to the Admiralty and Navy Board, corrosive sublimate as an anti-dry-rot application."[8]

The process of saturation under Kyan's patent was carried on in open tanks. Those erected for the Great Western Railway Company, at Bull's Bridge, near West Drayton, were 84 feet long and 19 feet wide at the top, 60 feet long and 12 feet 8 inches wide at the bottom, and 9 feet deep. The sides were of American pine plank 4 inches thick, supported on sills 12 inches by 10 inches, and upright framing posts 10 inches square. Ten of these posts were fixed in the length of the tank on each side, with diagonal braces 8 inches square. The tank was sunk in the ground, nearly level with the surface. The posts stood 2 feet above the sides, and transoms 15 inches by 12 inches were attached to them, to keep the timber down in the solution. Yet its tendency to float was so great that the transoms became cambered up $1\frac{1}{2}$ inch

[7] 'Memoirs of the Royal Academy of Sciences at Paris,' from 1699 to 1720. Vol. ii. p. 223.

[8] Ure's 'Dictionary of Arts,' &c., third edition, p. 811.

in the centre, and in one instance the whole tank was disturbed from its seat. A mast with a traversing boom was erected at one end of the tank, and used in removing the timber.[9]

The solution used for preparing the timber contains 224 lbs. of the corrosive sublimate to 1062 gallons of water, or about 1 lb. to five gallons. The cost of the process was stated, in 1836, to be twenty shillings per load of 50 cubic feet. Of this twenty shillings, one-half consisted of license, risk, and profit, and one-fourth was estimated for labour in filling and emptying the tank, and unloading. The remaining fourth part was for cost of the solution.[10] The sublimate was dissolved in hot water, and added to the water in the Great Western tanks just described, and the strength of the solution was tested with the hydrometer.

Subsequently, attempts were made to improve the efficiency of the solution by *forcing* it into the wood, instead of simply immersing the wood in the solution. For this purpose close tanks were substituted for open ones, and an injecting apparatus of force-pumps, &c., was added, besides air-pumps for previous exhaustion. A complete arrangement of this kind was fitted up for preparing the timber of the permanent way of the Hull and Selby Railway, and was fully described before the Institution of Civil Engineers in March, 1842. The following is quoted from the Report of this Paper, published in the 'Civil Engineer and Architect's Journal.'[11]

"The apparatus consists of two tanks, a reservoir, two force-pumps, and a double air-pump. The tanks are cylindrical, with flat ends, and are made of wrought iron plates nearly half an inch in thickness; they are 70 feet in length, and 6 feet in diameter: at each extremity is a cast iron door, flat on the outside, and concave on the inner side, provided with balance weights for raising and lowering it. Each end is strengthened by five parallel cast iron girders, whose extremities are held by wrought iron straps riveted on to the circumference of the tanks. Notwithstanding the great strength of these girders, several were broken by the pressure applied during the process. The vessels are lined with felt, upon which is laid a covering of close-jointed fir battens, fastened with copper rivets: this precaution is necessary to prevent the mutual deterioration which would arise from the contact of the iron and corrosive sublimate. There was originally only one brass force-pump, 2 inches

[9] 'Civil Engineer and Architect's Journal,' vol. vi. p. 205.

[10] Ibid.

[11] Vol. v. p. 202.

diameter and 6 inches stroke: this being found insufficient, another was added of 4 inches diameter, and henceforward a pressure of 100 ℔s. per square inch was easily obtained. The air-pump is 10 inches diameter and 15 inches stroke. Its construction is of the ordinary kind. The process is simple and rapid: the corrosive sublimate is first mixed with warm water in a trough, in the proportion of 1 ℔. of the former to two gallons of the latter; the clear solution is then poured off into the reservoir, where water is added till it is diluted to the proper point, which may be ascertained by an hydrometer: a more perfect test is the action of the solution upon silver, which it turns brown at the requisite degree of saturation. The operations of exhaustion and pressure employ eight men for five hours, the whole process occupying about seven hours, during which time from seventeen to twenty loads are Kyanized in each tank. It is desirable that the timber should remain stacked for two or three weeks after Kyanizing before it is used. It was found that about $\frac{3}{4}$ ℔. of corrosive sublimate sufficed to prepare one load (50 cubic feet) of timber. About 337,000 cubic feet of timber were Kyanized, the average expense of which, including part of the first cost of the tanks, was about 5*d.* per cubic foot. The timber was tested after the process, and it was found that the solution had penetrated to the heart of the logs."

The reading of this Paper was followed by a discussion upon the quantity of the solution absorbed by the wood, with and without the preliminary process of exhaustion, as practised for the Hull and Selby Railway; but in the absence of recorded experiments in which all other circumstances were the same, no agreed result was arrived at. The necessity of filling the pores of the timber, in order to make the process fully efficient, and the great difficulty of doing this by reason of the moisture which they already contained, was generally admitted. It was remarked also that the sublimate entered the *extremities* of the sap-vessels without pressure, but required pressure in order to penetrate *laterally*. Mr. Thompson, the Secretary to Kyan's Company, stated with regard to the strength of the solution, that "it was at first believed that 1 ℔. of corrosive sublimate to 20 gallons of water was sufficiently strong, and much timber had been so prepared; but experience had since proved that the strength of the mixture should not be less than 1 ℔. to 15 gallons, and he had never found any well-authenticated instance of timber decaying when it had been properly prepared at that strength: as much as 1 in 9 was not unfrequently used. In a cubic foot of wood prepared under a pressure of 70 ℔s.

per square inch, mercury had been found by the galvanic battery to have penetrated to the heart." The destructive action of the sublimate upon iron was also referred to.

The great want of complete experiments upon the peculiar action of this and other preserving matters upon timber, and the best mode of administering them, is apparent, and with particular reference to the adoption of timber as a material for railway viaducts and works. These experiments, it may be suggested, should also seek to determine how far the strength and elasticity of the timber is affected or impaired, according as the preparations are applied at the ends of the pores, so that these may become filled without crushing the intermediate fibres of the wood; or driven laterally into the pores through the resisting fibres.

With reference to the durability produced by this process, accounts are somewhat contradictory. How far success in this respect may be owing to careful and complete performance, or, on the other hand, failure be promoted by careless and incomplete Kyanizing, we have no means of determining. Upon the application of the process for the Great Western Railway, it was reported in August, 1843, that a part taken from the centre of one of the longitudinal timbers forming the base of the railway which had been Kyanized six years before, was "as sound as on the day on which it was first put down." But the reporter remarked, that during the process the strength of the solution had been carefully maintained. Upon first immersion the strength was 1 in 14, at a temperature of 62°; and the time of immersion for 7-inch timber was eight days: during this time the solution was kept at an uniform strength by pumping.[12] In this manner upwards of 40,000 loads of timber had been prepared, and the quantity of sublimate consumed was about $1\frac{1}{3}$ ℔. to each load.[13]

On the London and Birmingham Railway, on the contrary, the engineer reported, that the sleepers, which were all Kyanized, were, after lying three years, found to exhibit symptoms of decay,—that many of them had been removed absolutely rotten, and Kyan's process had been consequently abandoned.[14]

Sir William Burnett's process for preserving timber (patented March 19, 1840) consists in impregnating it with water saturated with the chloride of

[12] In open tanks, the timber being subjected to simple immersion, without exhaustion or pressure.

[13] 'Civil Engineer and Architect's Journal,' vol. vi. p. 356.

[14] Ibid. vol. vi. p. 306.

zinc. This is mentioned by Dr. D. B. Reid, in his 'Illustrations of Ventilation,' as the "most powerful of those materials that do not affect the texture or other qualities of the wood." And Dr. Reid adds that he has not yet "seen any specimens of wood or canvass that have resisted such trying circumstances as those that were protected by the muriate of zinc."[15]

In July, 1841, Messrs. Lang and Abethell, of Woolwich Dockyard, reported that three specimens of wood, viz., English oak, English elm, and Dantzic fir, which had been prepared by this process, had remained in the fungus-pit at Woolwich Dockyard for five years, and were still perfectly sound; while three similar specimens unprepared were all more or less in a state of decay.

The cost of this process, as announced by the Association formed for carrying it out, is as follows:

For preparing timber, round or square, including planks, deals, hop-poles, paving blocks, and railway sleepers, at the Company's station, Millwall,—fourteen shillings per load of 50 cubic feet, besides two shillings for landing and loading. One pound of the material which the proprietors supply for one shilling is said to be sufficient for ten gallons of water.

Bethell's process (patented July 11, 1838) is described by Dr. Ure[16] to consist in "impregnating wood throughout with oil of tar, and other bituminous matters, containing creosote, and also with pyrolignite of iron, which holds more creosote in solution than any other watery menstruum. The wood is put in a close iron tank, like a high-pressure steam boiler, which is then closed and filled with the tar-oil or pyrolignite. The air is then exhausted by air-pumps, and afterwards more oil or pyrolignite is forced in by hydrostatic pumps, until a pressure equal to from 100 to 150 lbs. to the inch is obtained. This pressure is kept up, by the frequent working of the pumps, during six or seven hours, whereby the wood becomes thoroughly saturated with the tar-oil, or the pyrolignite of iron, and will be found to weigh from 8 to 12 lbs. per cubic foot heavier than before."—"The effect produced is that of perfectly coagulating the albumen in the sap, thus preventing its putrefaction. For wood that will be much exposed to the weather, and alternately wet and dry, the mere coagulation of the sap is not sufficient; for although the albumen contained in the sap of the wood is the most liable and the first to putrefy, yet the ligneous fibre itself, after it has been deprived of all sap, will, when exposed

15 'Illustrations of Ventilation,' p. 74.

16 'Recent Improvements in Arts, Manufactures, and Mines.' 1844. p. 274.

in a warm damp situation, rot and crumble into dust. To preserve wood, therefore, that will be much exposed to the weather, it is not only necessary that the sap should be coagulated, but that the fibres should be protected from moisture, which is effectually done by this process."—"The materials which are injected preserve iron and metals from corrosion; and an iron bolt driven into wood so saturated remains perfectly sound and free from rust. It also resists the attack of insects."—"The expense of preparing the wood varies from 10*s*. to 15*s*. per load, according to situation and distance from the manufactories where the material is made."—"Common Scotch fir sleepers, which have been in use three years and upwards, look much better now than when first laid down, having become harder, more consolidated, and perfectly water-proof."

At a meeting of the Institution of Civil Engineers, in February, 1842, it was stated, that some piles at New York which had been saturated with coal-oil, perfectly resisted the attacks of the 'Teredo navalis,' in the same situations where Kyanized piles had been entirely destroyed by them. And Mr. Bethell, the patentee of this process, remarked upon the necessity of purifying the oil of tar from ammonia, that "in experiments he had made previously to taking out his patent for preparing timber with coal-oil, he observed that wood coated with common coal-tar soon turned brown, and decay ensued; ammonia produced the same appearance and effect. The refined coal-tar, as manufactured in London, is purified from ammonia by distillation, and found an excellent coating for wood."[17] The process has been adopted in preparing the sleepers for several of the railways, and on one or more has been substituted for Kyan's process.

Payne's process is described in the patent (dated July 9, 1841) to consist in impregnating the wood, or other vegetable substances, with a solution of metallic or earthy matter, by means of exhaustion and pressure; and then, by chemical decomposition, obtaining the preserving matters in an insoluble state, within the substance of the vegetable material under operation. As there are many metallic and earthy matters which are known as preservatives of vegetable substances from decay, and from burning with flame, the patentee does not confine himself to any particular solution; but in order to illustrate his invention more clearly, he states, that (with regard to metallic solutions) if the vegetable matter be impregnated with a strong solution of sulphate of iron,

[17] 'Civil Engineer and Architect's Journal,' vol. v. p. 169.

either hot or cold, he forces into it, by exhaustion and pressure, a solution of any of the carbonate alkalies, or of any other substance that will decompose the salt, and render the oxide of iron insoluble. With regard to earthy matters, supposing the vegetable material be impregnated with a strong solution of alum, he decomposes it by the employment of a solution of carbonate of soda, of a suitable strength for that purpose; or any other well-known means of decomposing the solution may be used, for the purpose of precipitating the alumina.[18]

This invention has been applied in preserving the timber used in the Royal stables at Claremont, and has been approved by the Commissioners of Woods and Forests, who directed Mr. Phillips, Professor of Economic Geology, to report upon the process. This Report was highly favourable to the utility of the invention.

Reverting to Plate X. of outlines of bridges, the situation for a railway bridge, shown in the figures 4, (A and B,) supposes that the extent of embankment or excavation is insufficient for the minimum height under the arch, and that hence a small quantity of earth-work will be needed in cutting, as shown at A, fig. 4,—or in approaches, as shown at B, fig. 4. Of such bridges an example or two will be found in the description of Plates.

For the purpose of forming a road of any kind beneath a high embankment, the viaduct may be commonly dispensed with, and a low tunnel-like bridge be adopted, having only the minimum height of arch. Of such bridges an example is given in the Plates. It may be remarked here, that considerable saving is effected by adopting them. Although the narrow cut through the base of the embankment requires, in order to support the sides, that the wing walls of the bridge be extended to the entire width of the bank, yet the quantity of masonry is much less than in an equivalent viaduct; and it may also be judiciously constructed in a rougher and cheaper manner. In these bridges it is however highly essential to secure an ample thickness and strength of arch, and also to employ cement in the building of it.

The accompanying Plates represent some of the most substantial and approved works included under this Section.

Plate XI.—Figs. 1 to 5 refer to a double-arched bridge, built at a small angle over the London and Birmingham Railway, and carrying a public road or

[18] 'London Journal of Arts,' vol. xxiii. p. 352.

street. The bridge is extended for a considerable length in the direction of the railway. Fig. 1 shows half the elevation. Fig. 2, half section, parallel with the face of the bridge. Fig. 3 is a partial plan, showing the lower part of the abutment wall, and is taken sectional through the intermediate piers which support the common impost of the two arches. Fig. 4 is a partial cross section through the crown of one of the arches, showing the construction of the arch, and parapets, and also showing the skewed backs from which the brick-work of the arch springs. These are cut upon the impost, and to the length of one or more bricks, so as to work in with the regular courses, and avoid the defective alternative of starting the arch with cut bricks and bats. Fig. 5 shows a portion of a similar cross section, having the recesses in the face of the abutment formed with inverts upon the face, and breaking the top line of footings. The footings of the abutments and piers are built upon a solid bed of concrete, about 18 inches thick. Against the elevation of this bridge a section is shown of the retaining wall, which bounds the cutting over which the bridge is built. The section, fig. 2, shows the manner in which the thrust of the arch, which is elliptical, having a rise of nearly a quarter of the span, is intended to be partly resisted by the solid ground adjoining, instead of being wholly sustained by the abutment. For efficiency this plan may be safely recommended; and as a judicious mode of rendering a flat arch safe, and thus dispensing with unnecessary height, this cannot perhaps be replaced by any cheaper method. In figs. 1 and 2 is also shown the dipped form to which the upper surface of the excavation should be trimmed, to keep the foundations dry, and lead the water towards central drains, as shown on Plate VI., and described in the Second Section.

Figs. 6 to 10 represent a small occupation bridge, adapted for the convenience only of cattle or cart-traffic.

Fig. 6 is a half section, and fig. 7, a half elevation. Fig. 8, a partial cross section. Fig. 9, a partial plan above the foundations. Fig. 10, a section of one of the wing walls, taken near the abutment. This tunnel-like bridge is adapted for any extent of embankment, with the precaution, if of great height, of giving the arch a little extra thickness, and strengthening it by a tie-bolt built in the crown of the arch throughout its entire length, and abutting by heads, screwed nuts, or keys, against its two faces. This bolt may for convenience be formed in links with secure weldings. The roadway beneath the bridge, 15 feet wide, is shown as divided into a cartway and a footway. An inverted

arch is turned in cement between the abutments, and cannot be well dispensed with in bridges built in such situations as here described. In these bridges the use of wing walls is imperative, unless the arch were carried forward to the extent of the bank, which would involve an unjustifiable expense; but if built of the strength shown in this example, these walls are fitted to answer their purpose in the best possible manner.

Figs. 11 to 15 exhibit a cattle bridge only, with brick arch, but faces entirely of stone, and thus adapted for a district where this material is plentiful. It is shown as if constructed in a bank about 9 feet high, but would require no modification except a thickening of the arch if built under a much higher one: a 9-inch invert is built between the abutments. The wing walls are shown as also faced with stone in courses.

Plate XII. represents two bridges built in rather different circumstances, but still sufficiently similar to admit a comparison between them of two styles of design, both of which have been much employed in railway bridges, viz., the single-arch with long wing walls, and the three-arch with intermediate piers.

Besides the reasons already stated in objection to retaining walls of all descriptions, the single-arch bridge is also more expensive in first cost, athough requiring less centering than the other. The wing walls of the bridge shown on the Plate are necessarily of great strength, to resist the pressure of the filling-in earth between them; and the same cubical quantity of brick-work may be so used as nearly, if not quite, to complete the three-arch bridge. In this case, if the bridge be in embankment, the whole of the filling-in earth-work incurs additional expense; and if in cutting, very little will be saved in earth-work in adopting the single-arch, while, on the other hand, the solid walls prevent the action of the air upon the slopes, which is found desirable for their hardening. And, moreover, the three-arch bridge facilitates vision along the line, and this is really essential to safety, especially over curves and in cuttings.

It must be observed that the economy in first cost of the three-arch certainly diminishes as the width of the bridge is increased, and we may conceive one so wide that the expense of the two additional arches should not be incurred, but in practice few such cases arise.

Figs. 1 to 7 represent a square bridge carrying an occupation road or way, 15 feet wide, over the railway at a point where the latter is about 5 feet below the original surface of the ground. Fig. 1 is a half elevation. Fig. 2, a half

section, parallel with the face of the bridge. Fig. 3, a partial plan, taken beneath the string-course, level with the crown of the arches. Fig. 4 embraces a partial plan of one of the abutments and one of the intermediate piers. Figs. 5 and 6 are cross sections through the wing of the abutment, one taken near the arch, the other through the battering pilaster at the end of the wing. Fig. 7 is a half cross section through the crown of the centre arch. The arches are semi-ellipses; the centre one 30 feet span, with a rise of 8 feet 6 inches; the side arches 28 feet 3 inches span, and rise about 7 feet 6 inches.

Figs. 8 to 14 exhibit a single-arch bridge carrying an occupation road, 15 feet wide, obliquely over the railway, which is here nearly level with the original surface of the ground. Fig. 8 is a half section, parallel with the face of the bridge, and showing the breaks formed horizontally and vertically in the back of the wing walls. This section also shows the arch, abutment, and brick backing to the arch. The backing to both of the bridges shown on this Plate may, however, be more efficiently disposed by inclining the top surface of it so as to be tangential to the crown of the arch, and fall thence towards the extremity of the abutments or centre of the intermediate piers. It is evident that a more equal resistance is thus obtained to the thrust of the arch, and a better disposition effected for getting rid of water from the brick-work. Fig. 9 is an elevation of half of the bridge, and shows a pilaster carried up vertically 6 feet 9 inches in width. This pilaster serves for the imposts to break against on one side, and for the battering wing walls on the other. On the acute side of the arch, the abutment as high as the impost stone is brought out at right angles with the skew of the bridge, and on the obtuse side the abutment is similarly brought forward, and formed to show an equal splay with that on the acute side. Up to this height, therefore, the work presents no internal angles. Above the impost, however, the faces of the arch and spandrils are set back, and thus form uniform angles with the projection of the pilasters. The section, fig. 8, shows the footings of the counterfort, inclined at right angles with the battering back of it; and if this inclined bed be observed throughout the courses in the counterfort, its efficiency will be increased, as already observed regarding retaining walls. Fig. 10 is a half cross section of the bridge, showing a stone coping and string-course; the latter not carried through the entire thickness of the parapet. By this method, however, the bond of the work is injured, and although stone is saved, cannot be recommended. Fig. 11 shows a partial plan above the arch. Fig. 12, a partial plan

above the foundations, showing the reduction of the wing walls. Fig. 13 is a half section of the arch and abutment, taken at right angles with the skew of the bridge, or as commonly called, 'on the square.' Fig. 14 shows a cross section through the wing wall near to the abutment.

Plate XIII. represents two substantial and handsome works on the London and Birmingham Railway; a bridge built over a river and sloping irregular valley, and one erected to carry the railway over a canal. Figs. 1 to 4 exhibit the former structure; figs. 5 to 10, the latter.

The bridge over the river consists of one main arch, 60 feet in span, and semicircular; and three semicircular arches, 17 feet span, on each side. The main arch has abutments each 14 feet thick. The bridge is 28 feet wide between the parapets, being adapted for a double line of rails to a gauge of 4 feet $8\frac{1}{2}$ inches. Arches are turned between the spandrils to reduce the weight on the upper part of the arch, while a solid backing of brick-work supports the haunches. The piers between the side arches show a width of 8 feet on the face of the bridge, but are reduced to 2 feet 3 inches by three intermediate recesses in the width of the bridge. Fig. 1 is a half elevation. Fig. 2 is a half section, parallel with the face of the bridge. Fig. 3, a half plan over the parapets; and fig. 4, a half plan below springing. Brick inverts are turned between the side arches, and the levels of these and of the footings are determined by the original surface of the ground, which falls rapidly on one side towards the river. The entire height from the level of the water to that of the rails appears to be about 53 feet. A thick bed of concrete surmounts the arches and the intermediate backing. The slopes of the embankment are at 2 to 1, and start from broad benches on the original surface of the ground.

Figs. 5 to 10 represent the canal bridge. Fig. 5 is a half section, parallel with the face of the bridge; fig. 6, a half elevation. Fig. 7 is a half cross section through the crown of the arch, and with the retaining wall of the towing-path removed. Figs. 8 and 9 show a half plan, taken above the arch in fig. 8, and above the foundations in fig. 9; and fig. 10 represents the construction of the foundations of the abutments. In this case the railway is embanked about 16 feet above the original surface of the ground, and the entire site of one of the intended abutments presented a shifting mass, evidently incapable of sustaining permanently the load which the abutment would put upon it. An artificial foundation of a most complete character was therefore provided. First, four rows of piles were driven; fourteen piles in each row,

and each pile about 20 feet long. The rows were 2 ft. 3 in. apart from centre to centre, and each pile was 2 ft. 4½ in. distant from the adjoining one in each row. Behind these four rows, seven other rows of piles, fourteen in each row, were driven, not vertically, but obliquely, as shown in fig. 5; and the tops of these were trimmed to a plane surface at right angles to their obliquity. A platform, partly horizontal and partly inclined, was then constructed upon the heads of these eleven rows of piles, thus: Over the pile-heads timber sleepers were fixed, corresponding in position with the rows of piles. Between these sleepers brick-work was built up to the level of the upper surface of the sleepers. Over the whole surface stout planking was then laid, and around the outer sides of the whole a row of sheet piling driven, with double walings bolted to it.

Upon the platform thus formed the abutment was built, consisting of stone in blocking courses, with brick-work above. The line of the extrados of the arch, which is a circular segment, 35 feet span and 6 feet rise, is continued down nearly to the ground, the materials of the entire abutment being thus disposed in a triangular form. The towing-path is retained by a dwarf wall, built upon piles. The design of this bridge is suited for a stone district, or one where that material may be cheaply procured.

In Plate XIV. are exhibited the complete details of one of the interesting works on the London and Birmingham Railway, viz., the viaduct over the river Avon and its valley. Fig. 1 is a general sketch of the elevation of this structure. Fig. 2 is an enlarged elevation of one of the main and one of the side arches, with enough to show the design and dimensions of the intermediate piers, of which fig. 3 is a partial plan above the foundations. Fig. 4 is a half cross section through one of the piers; and fig. 5 is a section taken parallel with the face of the bridge through one of the end abutments, the three small arches adjoining, and the hollow pier which separates these from the main arches. This viaduct, of which the total length is about 350 feet, consists of nine semi-elliptical arches, 24 feet span, and 7 ft. 6 in. rise, and three semi-circular arches at each end, of 10 feet span, faced entirely with stone. Each of the six end arches has a brick inverted arch between the piers above the foundations, which are carried along uniformly in a solid bed beneath these arches, with such steps and at such levels as the nature of the substratum required. The three middle arches have an inverted arch of brick-work, which forms an artificial channel for the river. This invert is façed at each end with a row of

sheet piling, driven through the loam into a bed of strong gravel beneath. All the foundations which do not reach this gravel are built upon thick beds of concrete, and a layer of the same material covers the whole of the arches, forming a level bed for the gravel in which the sleepers of the railway are laid. The figures 4 and 5 show the iron down pipes by which the work is drained.

Plate XV. shows the construction of iron girder bridges, and other works upon the London and Blackwall Railway. Figs. 1 to 9 refer to bridges for limited heights. The depth of girders in this case being limited to 14 inches, they are introduced in pairs, and are cast with projecting ribs on the sides, leaving a space for a wrought iron bar, curved in the manner of an arch, 3 inches by 2 inches, which bar abuts at the ends against suitable shoulders formed in the castings. The spaces between the girders are filled by cast iron arched plates, the concave sides of which form the soffit of the bridge. These plates have fillets on the sides, and are bolted through the girders, resting upon their lower tables. The girders are 28 feet in length, bearing 18 inches at each end upon the abutment walls. Fig. 1 is an outside elevation of one of the girders; fig. 2, an inner elevation; fig. 3, plan of two coupled girders; fig. 4, sectional through the covering plates at the crown, and against the fillet, showing half-lap joints. Figs. 5, 6, and 7 will explain the construction of the parapets, string-course, &c. The string-course and parapet standards are of cast iron, secured by lugs and bolts to the girders. The standards are formed with a groove on each side for receiving slate slabs, 2 inches thick, which form the panels of the parapet; and the whole is surmounted by a cast iron capping. Figs. 8 and 9 are sections through two pairs of the girders and the arched covering plates and joint.

Figs. 10 to 14 represent one of the 40-feet iron bridges erected upon the same railway. Cross timbers, 12 inches square, are fitted between the girders, and supported on their lower tables; and upon these timbers the chairs for the rails are spiked down. The girders are 43 feet long, bearing 18 inches on the walls at each end, and upon stone corbels built in the walls for a further length of about 2 feet. The cross timbers are placed 3 feet apart between centres on the line of railway; and at double this distance in the intermediate and side spaces. The face girders are parallel, moulded outside, and surmounted by an ornamental cast iron railing. The inner girders are curved on the top table, 2 feet deep at the centre, and 9 inches at the ends.

Figs. 15 to 18 exhibit the ordinary construction of the arches upon which

the Blackwall Railway is supported. They are segments of circles, 30 feet span and 10 feet rise, with 3 ft. 6 in. piers, and 26 feet deep. The brick-work of the arch is 2½ bricks, or 1 ft. 10½ in. thick; stone string-course, and open iron railing. This example is thought worthy of record, showing a construction which has sufficed for a constant traffic of carriages and goods' trucks without locomotives.

On Plate XVI. are shown the construction of an iron girder bridge, and of a timber foot bridge, both on the London and Birmingham Railway. Figs. 1 to 7 refer to the former structure; and figs. 8 to 14 refer to the latter. The iron girder bridge has two rows of arches, each 25 feet span and 2 ft. 6 in. rise. The outside girders are ornamental, but are aided by other girders immediately within, shown at fig. 3. The ordinary inner girders are shown at fig. 4. Fig. 2 is a cross section through the face and part of the length of the bridge, which is much extended in this direction, to carry a wide junction of roads above. Two wrought iron tie-rods, shown in this figure, extend throughout the whole length of the bridge. Fig. 5 shows a panel plate, fitted to cover the meeting of the two outside girders, which are bolted together over the intermediate pier, as seen in fig. 1.

For supporting a mere foot-traffic over a railway, the bridge shown in figs. 8 to 14 is an example of cheapness and efficiency. Two piers of masonry are built, one on each side of the line, and two timbers, $12'' \times 9''$, and about 40 feet long, are thrown across the piers, and bolted down upon them by bolts built in. Iron distance pieces, shown at figs. 8 and 9, are fixed between the timbers; 4-inch plank is laid upon them, and posts, braces, and top rail, properly connected with tenons and iron straps. Wooden steps are added on either side, with hand-rail and braces. The width of the bridge between the railings is 4 feet 6 inches.

Plate XVII. shows the construction of the timber-arched bridges, constructed on the Newcastle and North Shields Railway, which have been described in the preceding part of this Section.

Plate XVIII. exhibits three forms of timber bridges or viaducts, two of them being trussed, and the other formed of plain girders, constructed of baulks of timber bolted together. Figs. 1, 2, and 3 show one bay of a bridge built over the river Dove, and the contiguous valley, upon the line of the Birmingham and Derby Railway. Each truss consists of two half-timbers, each 7 by 14 inches, separated by a vertical space of 1 foot 7 inches. The span from centre

to centre of the piles upon which the bridge is erected is 20 feet, which is divided into four equal spaces by cast iron struts or queen-posts, through each of which two iron rods pass. These rods pass also through the half-timbers, and have screwed nuts. The iron vertical struts are also formed with sockets to receive the ends of diagonal struts of timber, each 14 inches by 4 inches. Each bay consists of five of these trusses, which are supported upon transverse sills, 12 inches by 6 inches, resting upon the heads of the piles, there being five piles corresponding with the trusses in each row, forming the width of the bridge. The central space between the centres of the trusses is 6 feet, and the side spaces 4 feet 11 inches each. Diagonal braces, 4 inches square, are fixed between the trusses over the transverse sill. The flooring consists of 3-inch planks, laid transversely, and thus binding the five trusses together. The chairs to support the rails are bolted through the flooring. The parapet railings consist of wooden posts, 4 inches square, fixed 3 feet 4 inches apart, and bearing a wooden hand-rail. The posts are tenoned into cast iron shoes sunk in the flooring. Figs. 9, 10, and 11 show front and side views of the two forms of struts employed, and figs. 12 and 13 show the shoes for the railing-posts.

Figs. 4, 5, and 6 represent one bay of a timber viaduct built over the valley of the Tame and Trent rivers, upon the same line of railway. The span is, in this case, 24 feet, but each bay consists of one central span of 21 feet, and one side span of 3 feet. The piles, of which a double number is thus required, are 9 inches square. The trussing consists of a tie-beam, 7 inches by 14 inches, and a top whole-timber, 14 inches square, halved at the ends. The projections of the central part have abutting struts, 7 by 14 inches, extending diagonally to the ends of the tie-beam into which they are tenoned. Over each pile a post, 7 by 14 inches, is fixed between the top timber and tie-beam, and two diagonal braces, each 14 inches by 4 inches, are crossed between them, over the side span of 3 feet.

There are five trusses in each bay, and they rest upon a transverse sill, 7 by 14 inches, supported upon the heads of the piles. Diagonal braces, 7 by 7 inches, are crossed between the trusses, over each row of piles, and a flooring of 3-inch planking is laid transversely. The ends of the flooring planks are stopped against a wooden nosing or string, upon which shoes are fixed to support a railing similar to that last described. Figs. 14, 15, 16, and 17 show side and top views of cast iron sockets, which were intro-

duced at the junctions of the timbers of the trusses at the points A and B, as marked.

Figs. 7 and 8 show a transverse and longitudinal view of one bay of the timber viaduct which forms the Bricklayers' Arms branch of the South Eastern Railway. The span is 20 feet between the centres of the piles or posts. Each row of piles contains three, of which the central one only is vertical, the side ones being placed battering outwards at the bottom, at the inclination of 3 inches to a foot. The piles are 13 inches square, having a pair of waling pieces, each 12 by 6 inches, bolted against them, and struts, 9 inches by 9 inches, are fixed between the centre and side piles.

Each row of piling carries two transverse timbers, 13 inches square, one bolted upon the other, and these support six solid girders of timber, the two outer ones being 26 inches deep by 6 inches thick, to carry the ends of the flooring (which is 4 inches thick) and the railing, and the four intermediate girders, being of the same depth, but 13 inches thick, formed of two whole baulks, and being longitudinal bearers for the rails, which are flanged in the manner of the Great Western rails, and bolted to the flooring. By the side of the rails, wooden guard-rails, 6 inches square, are bolted down to prevent the wheels escaping from the rails.

Plate XIX. illustrates the construction of some of the timber bridges which have been constructed in America for the Utica and Syracuse Railway, the works upon which line are fully described in Mr. Weale's work on Railways.[19] Figs. 1 and 2 show the construction of bridges with 30-feet bays between centre of posts, which are 12 inches by 12 inches, and placed in rows, seven of them occupying the width of the bridge, which is 26 feet over. The trussing consists simply of half-timber girders, 14 inches by 7 inches, with two struts notched into the under side of the beam, which abut against and are bolted to the upright posts which constitute the piers: these are built upon masonry 2 feet in thickness, and diagonal braces, 12 inches by 3 inches, are bolted one on each side against the pier-posts. The flooring is $2\frac{1}{2}$ inches in thickness, bolted down to the half-timber girders. The railing consists of posts 5 inches square, fixed 3 feet 9 inches from centre to centre, and a hand-rail also 5 inches square. The girders are carried upon a cross sill, 12 inches square, notched down upon the head of the pier-posts.

Figs. 3 and 4 show an economical method of constructing abutments, partly

[19] 'Ensamples of Railway Making,' 1843.—Weale.

of masonry and partly of timber, and adapted for arches of large span; the figures exhibit one adapted for a span of 82 feet, built over the Oneida Creek: the foundation consists of white pine planking, 6 inches thick, laid longitudinally in the direction of the bridge, with a second layer laid across the first, and of the same thickness. Upon this foundation the masonry is erected, the height of which is about half that of the entire structure, and is built with faces battering 1 in 12, and the thickness at the top 7 feet, or about one-twelfth part of the span.

The timber framing which forms the upper part of the abutment consists of two rows of upright posts, 12 inches square, properly framed into a rectangular framing at top and bottom, made of timbers 12 inches square. There are seven posts in each row, or fourteen in each abutment: this framing is strengthened by braces, 9 inches by 3 inches, fixed diagonally in rows on the four sides of the framing, and also on the top and bottom of it, and the whole is put together with oak trenails, 1 inch diameter, and from 12 to 18 inches in length. The quantity of timber required for a framing of this construction and size will be about 450 cubic feet, or 9 loads.

Figs. 5, 6, 7, and 8 exhibit trusses adapted for spans of 30 and 40 feet, and employed upon the Utica and Syracuse Railway. Fig. 5 shows the elevation of the 40-feet truss, and fig. 6 a cross section, with a width of 22 feet between the trusses; this, however, would be insufficient for a double line of rails laid to the 4 feet $8\frac{1}{2}$ inch gauge. The trusses are supported upon double rows of posts, 12 inches square; the rows being 2 feet apart, and the posts placed 4 feet apart between their centres in the row: each row of posts is capped by a cross sill, 12 inches square, notched down upon them. These carry the trussed beams, which are 15 inches deep, and formed of three thicknesses of four inches. Five intermediate timbers are also supported upon these sills, and serve, together with the trussed beams, to carry transverse timbers, each 12 inches by 7 inches, upon which the flooring is laid. The posts which form the abutments are cased externally with 3-inch oak plank, which is not shown in figs. 5 and 6. The quantity of timber in one 40-feet bay of a single-track bridge, 11 feet in the clear between the trusses, as given in detail by Mr. B. F. Isherwood,[20] amounts to 575 cubic feet, or $11\frac{1}{2}$ loads, and the iron-work in bolts, washers, and bands, will be 568 lbs.

[20] 'Description of the Mechanical Works on the Utica and Syracuse Railway,' published in the 'Ensamples of Railway Making.'

Figs. 7 and 8 show an elevation and half cross section of a 30-feet truss, supported upon abutments formed of single rows of piles framed into a lower sill and a cap above them, with inclined braces at the ends, having the same inclination as the embankment. Mr. Isherwood gives the quantity of timber for a single-track bridge of 30 feet span, 11 feet in the clear between the trusses, and of the construction shown in these figures, at 423 cubic feet, or about 8½ loads, with 280 lbs. of iron in bands and stirrups.

These trusses, as adopted on the Utica and Syracuse Railway, are boarded up, coped and painted, and the quantities of timber given above for each bridge include this boarding and coping-posts for rails, &c., complete.

On Plate XX., figs. 1 and 2 exhibit a timber bridge with three bays, each 40 feet span, adapted to carry a roadway over a railway; the abutments and piers are of masonry, and the roadway is partly suspended from the trusses. The width between the parapet railings is 12 feet; the trusses consist of a half-timber beam, 12 inches by 6 inches, with two queen-posts, 9 inches by 6 inches, carrying a tie-bar, 9 inches by 6 inches, and two diagonal struts, 12 inches by 6 inches. Diagonal braces, 6 inches by 6 inches, are fixed between the queen-posts. Over the abutments, upright posts, 6 inches by 9 inches, with the top rail, 6 inches square, complete the framing. A piece of timber, 9 inches by 9 inches, is built in the abutment, and projects 2 feet 3 inches on each side beyond its face, for the purpose of receiving the ends of struts, 4 inches square, to strengthen the posts of the framing. The roadway is formed with metalling, laid upon a longitudinal plank flooring, supported upon cross sills, 9 inches by 4 inches, and fixed about 2 feet 8 inches apart from centre to centre; the ends of these sills are notched down upon the half-timber girders. The whole of the framing is put together with wrought iron screwed bolts with nuts and washers, and the heads of the queen-posts and ends of struts and tie-beams are connected in iron sockets.

Figs. 3, 4, 5, and 6 show the method of constructing timber bridges which was patented in 1835 by Ithiel Town, an American engineer. The following is quoted from the description given of these bridges in Mr. Weale's work.[21]

"The form of this truss will be seen from the elevations in fig. 3, which are applicable to a double-truss bridge on Mr. Town's principle, there being a double truss on each side of the roadway. Each truss consists of a series

[21] 'Bridges,' vol. ii. Supplement, p. lxxvi.

of diagonal or truss braces inclined at an angle somewhat steeper than 45°, crossed by another series inclined at the same angle in an opposite direction, and of a horizontal string-piece on each side at top and bottom, the whole firmly secured by wooden trenails of hard wood, as shown in fig. 3. The height of the truss is usually about one-tenth or one-twelfth the span of the bridge or distance between the piers. The plan in fig. 5 shows the way in which the double trusses are put together with string-pieces between them, and the transverse section shows one end of a pier with the double truss erected on it, and part of the roof, extending across from one double truss to the other.

"There are two very distinct methods of building these bridges, according as the roadway is placed at the top of the trusses or on the level of the lower string-pieces. The first section in fig. 6 shows the first construction, and the second shows the roadway at the bottom, with the whole height of head-room, confined to the depth of the trusses by the beam which rests on them at the top. The first construction is that which will commonly be advisable when the span is not great, and when, consequently, it would be unnecessary to employ trusses of so great a height as 15 feet, which is about the minimum of head-room required for railways. In the case of wide roads also which are not railways, and where, consequently, suspension posts in the centre would be inadmissible, the first construction will be invariably necessary, however wide the span, unless additional strength be given to the floor beams.

"The second mode of construction has the advantage of enclosing the road-way both by a side and top covering or roof, and in both the designs exhibited in fig. 5 a wooden boarding, to protect the trusses from the weather, is shown on each side of the bridge.

"The trenails used for securing the truss-braces and string-pieces together, should be of white oak, or other hard wood, and in the large bridges of America are usually 2 inches in diameter. They should be exactly fitted to the augers used for boring the holes, so that when seasoned they may drive tight and make solid work. The patentee observes, that the trenails may be made different ways, but the best and most economical is to saw them out square from plank, with a circular saw, and then turn them with a small lathe, attached to some water or other machinery. They should be unseasoned, to be easily made, but must afterwards be well seasoned before driven into the work: they will season quickly, or may be kiln-dried. Tallow or oil, &c., may be rubbed on them to make them drive more easily, if necessary.

"In America, there are already many of these bridges, on a scale of magnitude truly gigantic. Among the most important of these is the one erected by the celebrated engineer Moncure Robinson, Esq., for carrying the Richmond and Petersburgh Railway across the falls of James River at Richmond. The length of this bridge across the river is 2900 feet, and the trusses are supported on eighteen granite piers, the distances between the piers varying from 130 to 153 feet. The piers are founded on the granite rock over which the rapids flow. Their height above the surface of the water is 40 feet, and they are carried up with a batter of 1 inch in 2 feet vertical, up to this height of 40 feet above the water, where their dimensions at top are 4 feet in breadth by 18 in length. The masonry consists of regular courses of stone, dressed on the beds and joints, but left rough or merely scabbled on the outside faces. The floor in this bridge is on the top of the truss frames, and the depth of these being 20 feet, the roadway is carried horizontally across the river at an elevation of 60 feet above the water. This bridge was completed in September, and its cost was about £24,200 sterling.

"In addition to this great work on Mr. Town's principle, executed by Mr. Moncure Robinson, may be mentioned another on the same principle, across the Susquehannah, 2200 feet in length, with spans of 220 feet; besides several others.

"These bridges may be constructed of any kind of timber, however soft, provided planks of about 27 feet in length can be sawed out of it. White pine, spruce, and poplar, have been extensively used in America; but oak is objected to on account of its tendency to spring or warp, if not well seasoned."

Plate XXI. shows two varieties of trussing adopted upon the Utica and Syracuse Railway for trusses of large span, and adapted for double-track lines: the abutments for these trusses are of masonry. The 86 or 88-feet span, shown in figs. 1 and 2, has a pair of timber arches bolted against the exterior of the truss, which descend below the stringers, and thrust against the stone abutments in recesses formed for them; they are also fastened to the end posts, which are produced downwards for that purpose. In casing up the bridge, the arches were cased separately, and moulded. The quantity of timber for a double-backed bridge of three trusses, and constructed as shown in figs. 1 and 2, will be, according to Mr. Isherwood, 2953 cubic feet, or about 59 loads; and the total weight of iron, in bolts, bands, &c., 4328 lbs.

Figs. 3 and 4 exhibit the bridge by which the railway is carried over the

Oneida Creek: the span is 84 feet. The following extracts from the specification for this work will sufficiently explain its construction. "The abutment from the top of masonry shall be carried up to the level of the bridge stringers by a trestle-work of wood, constructed as follows:

"Two parallel vertical frames shall be erected at a distance of 3 feet asunder; they shall be strongly braced and united at top and bottom by cross ties. Each frame shall consist of a sill and cap-piece, separated by a distance of 14 feet. The sill and cap-piece of each frame shall be united by seven vertical posts tenoned into them, and well trenailed. Upon the outside of the posts, braces shall be pinned. The cross ties which unite the frames at top and bottom shall be dovetailed 4 inches into the sills and cap-pieces.

"The posts shall be so disposed, that one pair shall be immediately beneath a bridge truss. The three pairs directly under the bridge trusses shall be stiffened by cross braces, pinned against either side. The timber to be of sound white pine.

"The superstructure of the bridge is to be composed of three parallel vertical trussed frames, placed upon the foundations at right angles, and separated from each other by distances of 11 feet. The trussed frames and the timbers to be firmly bolted together. The flooring beams are to be placed at right angles to the trussed frames. The joints of the arch-pieces to be in the line of radii to the arc. The string timbers to be spliced with three splicing bars to each joint; said splicing bars to be 11 feet long, pierced with holes, and fitted with spurs on the ends: one hole in each end of every bar is to be so placed that the bolt will pass through the adjacent post. A splicing timber, 5 inches by 18 inches, and of such length as will fill the space between the posts, shall be inserted between the stringers, and the bolts shall be screwed until all the timbers are forced into close contact.

"The floor is to be formed with sound $2\frac{1}{2}$ inches thick white pine plank, laid edge to edge, and firmly spiked to the floor beams. The sides of the trussed frames are to be cased up with sound, well-seasoned white pine tully boards, planed, matched and nailed on vertically edge to edge in close contact. Fuming pieces are to be interposed between the casing and truss frame. The trusses to be coped with sound white pine plank, projecting 2 inches over their sides: the upper surfaces of said plank to be properly bevelled for throwing off the water, and the under surfaces to be wrought with a groove."[22]

[22] 'Description of the Mechanical Works on the Utica and Syracuse Railway,' published in the 'Ensamples of Railway Making.'

The figures on Plate XXII. show a variety of centres adapted for elliptical and segmental arches, and which have been adopted in the construction of several railway works. Figs. 1, 2, and 3 show the kind of centering and scaffold made use of in constructing the masonry of tunnels. Fig. 3 is a side view of one of the two framings upon which centres are supported. Fig. 4 shows a centering for an elliptical arch of 40 feet span, and is adapted for cases in which the abutments are very low, or an unusual height is required to be left clear while the work proceeds; but this form cannot be recommended except in cases where these conditions are imperative. The centerings shown in figs. 5 and 6 are also adapted for spans of 40 feet, and both also require intermediate supports the same as in fig. 4, between those at the extreme ends. Fig. 7 shows a centering for a span of 40 feet, but in which the width is not interrupted by having intermediate supports: an available height beneath the centering is still preserved, equal to that shown in fig. 6. Fig. 8 shows a centering for a 30-feet elliptical arch. Fig. 9 shows a centering for a 60-feet segmental arch, in which it was attempted to secure a high space for traffic beneath the work, without using any intermediate supports between the springing points of the centre. In this case, however, the construction was not found sufficient, and struts were obliged to be introduced in the position shown by the dotted lines, in order to prevent the centering from giving way.

In constructing bridges over cuttings it is sometimes practicable to dispense altogether with centerings. On the Birmingham and Gloucester Railway a bridge was built in this manner of blue lias limestone. The span is 60 feet, with a rise of 10 feet; the arch is composed of very small stones, from 3 to 5 inches thick, and squared to about 9 inches long and broad. "The material of the cutting where the bridge is situated consisted of weak slate and clay; consequently the mode of construction was subjected to a severe test. The abutments being completed to the springing height, the ground was cut away roughly to the form of the arch; seven rows of pegs were then inserted, with their upper ends correctly designing the proper curve; a line of planks, 3 inches thick, was laid transversely beside each row of pegs, and upon them were placed lines of battens on edge, gauged to the exact profile of the bridge; the earth was consolidated, and a flooring of battens laid over all to form a true bed for the soffits to rest upon.

"From the absence of parallelism in the lias stones, their varying thickness, and the difficult adhesion to the mortar, it was deemed necessary to introduce

seven transverse bonds of freestone, which imparted to the whole structure a tendency to settle in the lines of the radii of the arch, and also prevented any rent in the lias masonry from proceeding to a dangerous extent: these freestone bonds were firmly fastened with iron cramps. The face has a batter of 1 in 9, from the springing to the string-course, in order to counteract any tendency to bulge towards the faces, or in the line of the least resistance. The base was also extended, and the crown narrowed, which gave a concave form to the string-course. The whole arch being filled in with the full depth of stone-work on each springing, and the bonds of freestone all placed, the lines of each between the second and third bonds were keyed up, and then those between the third and centre bond, which thus apparently formed the key-stone.

"The earth centre was removed by cutting a heading 4 feet 6 inches wide, directly beneath the key-stone, and then gradually excavating on either side uniformly towards the abutments, stopping at certain intervals to allow any settlement to take place.

"By proceeding thus, as successive portions of the arch were left to their own bearings, regular compression ensued, and a small portion only of the work was exposed to fracture from inequality of pressure: the rising of the haunches, which generally accompanies any undue depression of the crown, appeared by this method to be entirely avoided." [23]

The settlement of the arch did not exceed $2\frac{1}{2}$ inches, and the experiment appears to have answered completely, having saved time, and also the expense of the usual wooden centre, beside which advantages, the bridge was ready when the cutting reached it.

In a bridge built over the Dublin and Drogheda Railway on the lattice principle, wrought iron has been introduced. This bridge is constructed over an excavation 36 feet deep. The span is 84 feet in the clear, and the two lattice beams are supported at each end on stone abutments built in the slopes.

These beams are 10 feet in depth, and are formed of two series of flat wrought iron bars, $2\frac{1}{2}$ inches by $\frac{3}{8}$ of an inch, crossing at an angle of 45°. At a height of 5 feet 6 inches above the lower edge, transverse bearers are fixed, and upon these the planking for the roadway was laid.

These bearers were formed of $\frac{1}{4}$-inch angle iron, 6 inches deep, and placed

[23] Minutes of Proceedings of Institution of Civil Engineers, printed in 'Civil Engineer and Architect's Journal,' vol. iv. p. 394.

2 feet apart. The beams were cambered 12 inches in the centre. The total cost of the bridge, including the masonry of the abutments, was £510. A description of this bridge was presented to the Institution of Civil Engineers in 1844.

The Victoria viaduct, on the Durham Junction Railway, "consists of four large and six small arches: the river arch is of 160 feet span, the adjoining arch is only 144 feet, the next arch on either side is 100 feet, and the three land arches on each side 20 feet in span; the middle pier is 23 feet 9 inches, and the other large piers 21 feet 6 inches in width; the length of a pier is 54 feet from point to point, and above the springing of arches 31 feet in length. Each pier has three courses of footings, altogether 5 feet high; the piers are not solid, but built with cross walls up to the springing level; over the arches are introduced spandril and cross walls; the whole being flagged over to receive the road materials. The piers are grounded on the solid rock, but the south abutment, being over quicksand, required to have an artificial foundation of piles, sleepers, and 3-inch Memel planking, in two thicknesses; the piles are of Scotch fir, 10 inches diameter and 14 feet long, and driven 3 feet apart. The lowest part of the foundation is 40 feet below the ordinary flood level. The whole length of the bridge is 811 feet 9 inches; and the top width, including parapets, which are solid and 4½ feet high, 23 feet 3½ inches."—(Whishaw.)

The cost was £38,000. The quoins of the two larger arches are of Aberdeen granite; all the rest of the bridge is built of stone from Pensher Quarry, in the neighbourhood.

On the Great Western Railway there are four bridge works of considerable extent, viz., the Wharncliffe viaduct, over the Valley of the Brent,—the bridge over the Thames, at Maidenhead,—the Bath viaduct,—and the bridge over the Avon. The Wharncliffe viaduct is of brick-work, with stone imposts, cornices, and copings; it has eight elliptical arches, each 70 feet span and 19 feet rise, built in rings; they are 3 feet thick at the crown, and increase to nearly double this thickness at the haunches.

The piers are in hollow panels, and average 13 feet thick. The height from the ground to the springing is 40 feet 6 inches, from bottom foundation to top of parapet, 81 feet. The clear width between the parapet is 30 feet.

The Maidenhead bridge is built chiefly of brick-work, and consists of two elliptical arches over the river, each 128 feet span, with a rise of only 24 feet 3 inches; two arches adjoining these, each 21 feet span; and six end arches,

three on each side, each of 28 feet span. The central pier is 30 feet thick. The principal arches are 63 inches thick at the crown, and 85 inches at the haunches.

The Bath viaduct consists of sixty-five segmental arches, varying in span from $19\frac{1}{2}$ to $20\frac{1}{2}$ feet, and built entirely of Bath stone. The arches are 3 feet thick at the springing, and 2 feet at the crown.

The bridge over the river Avon is constructed of timber framing on stone piers; it consists of two openings, each 89 feet wide, and rising 16 feet 9 inches.

A cast iron bridge, built for carrying the Birmingham and Gloucester Railway over the river Avon, is remarkable for the construction of the piers. The bridge consists of three segmental arches of cast iron, each 57 feet span and 5 feet 2 inches rise. The arches are "formed externally of cast iron plates or caissons, filled for the first 12 feet from the bottom with solid masonry or concrete, upon which is built hollow masonry to support the cap-plates, which carry eight pillars on each pier, with an entablature, to which are attached the ends of the arches, which, with the caps, pillars, and entablature, are of cast iron. The abutments at either end are of masonry.

"The caissons are, at the bottom, 41 feet 6 inches long, and 16 feet wide, with semicircular ends, tapering upwards for 12 feet on all sides to 34 feet 6 inches long, by 8 feet 6 inches wide, from whence they rise perpendicularly for the remaining 8 feet 9 inches. They are constructed of cast iron flanched plates, $\frac{3}{4}$ inch thick, screwed together by bolts, and the joints made with iron cement. The total weight of each caisson is about 28 tons.

"The bottom of the river at the site of each pier having been prepared by a scoop-dredger, worked from a platform erected upon piles, the lower row of plates for the caisson was put together, and suspended in the water by iron rods, while the other rows were added, gradually lowering the whole as the work proceeded, until the bottom rested on the bed of the river. A quantity of clay was then thrown round the outside, which formed a joint so impervious to water, that with two pumps, each of $5\frac{1}{2}$ inches square, the caisson was emptied in six hours, and was afterwards kept dry by one pump, which was worked occasionally during the subsequent excavations withinside the caisson.

"The total cost of the bridge, including iron-work and painting, masonry, subsequent repairs to the walls, and superintendence during construction,

was £10,192; and the weight of cast and wrought iron employed was about 520 tons." [24]

On the same railway a wooden lattice bridge, on the American principle, has been constructed over a cutting near Bredon. This bridge is 117 feet in span, $17\frac{1}{2}$ feet wide in the clear, and about the same height.

The Manchester and Birmingham Railway is carried over Fairfield Street, at Manchester, by a bridge formed of six cast iron ribs, each of which extends to a length of 129 feet 6 inches, and has a versed sine of 12 feet. These ribs are carried in cast iron abutment sockets, built in masonry: from these the ribs spring at right angles with the direction of the railway; but the street beneath crosses at an angle of $24\frac{1}{2}°$, and the span between the abutments, measured at right angles with the direction of the street, is only 53 feet 5 inches. The whole weight of iron in this arch is stated to be 540 tons.

The cast iron bridge which carries the London and Birmingham Railway over the Regent's Canal is 50 feet span, and adapted for four lines of rails. It consists of girders parallel at top and bottom, but having an arch cast in them with intermediate open spaces between this arch and the top and bottom lines. Each girder is cast in two pieces, bolted together, each 25 feet long, besides the length which bears within recesses formed in the abutments. Two of these girders are fixed parallel to each other, and about 3 feet apart. This pair of girders constitutes one rib, of which there are three, placed parallel, and about 28 feet apart between centres; there being two lines of railway between each two ribs. Below each of the outer ribs there are two horizontal tension rods, and below the middle rib there are four similar rods. These rods, which are of wrought iron, 3 inches in diameter, are secured at the ends of the girders in sockets with keys and gibs, and they have also intermediate couplings by which they may be tightened. Between the two girders which form each rib cross bracing frames of cast iron are fixed, at about 6 feet apart. From these frames vertical rods, $2\frac{1}{4}$ inches diameter, are suspended in sockets and held by keys. These suspension rods pass through sockets cast in the ends of cast iron girders, which they thus support, being retained by keys below; and upon these transverse girders the oak bearers for chairs and rails are fixed. Cast iron covering plates, of a lattice pattern, are fitted in between the rails. The two outside girders are ornamented with open bands or fillets of cast iron, bolted to

[24] Minutes of Proceedings of Institution of Civil Engineers. January, 1844.

the girders in lengths. Cast iron plates cover the spaces between the girders, in each rib, occupied by the bracing frames. Detailed engravings of this structure will be found in the 'Public Works of Great Britain.'[25] Two bridges of similar construction have been built at Leeds, one of which is 112, the other, 152 feet span.

In the course of railway making, many oblique or skew bridges have been built in an economical manner by using cast iron girders, as in that on the Manchester and Birmingham line just described. In these cases the abutments merely require recesses or notches to be formed in them, giving a square bearing for the abutment plates, so that these may bear with their entire rectangular surface. Many beautiful examples of oblique bridges of masonry may however be instanced among railway works. On the London and Birmingham line the railway is carried over the turnpike-road, at an angle of 32°, by an oblique bridge, built of bricks, with stone skew-backs, voussoirs, string-courses, and copings. The arch is 21 feet span on the square, and 39·627 feet on the oblique face. The acute angle of the voussoirs is cut off at right angles to the face of the arch, and the cutting is gradually diminished to the opposite or obtuse quoin, where it vanishes. Thus no angle less than a right angle is presented on the surface of any part of the work.

On the Croydon and on the Midland Counties Railways, brick bridges have been built in parallel sections of an arch which is square with the road or railway to be carried. On the latter railway a bridge of this kind is built over it, having these parallel ribs of brick-work about 4 feet broad on the square, elliptical in form, and 42 feet 6 inches span, with a rise of 11 feet. The plan of the abutments thus presents a series of notches or steps, from each of which one of the brick ribs springs. This construction, however, requires, in cases of great obliquity, either very thick arches or very narrow ribs of brick-work, unless intermediate spandrils are introduced to fill up the spaces between the soffit of one rib and the extrados of the adjoining one. Thus an extra expense, or an inferior bonding and strength, will be incurred.

A method has been adopted of forming oblique arches by building the central part of them as square arches, springing at right angles from the abutments, and filling in the ends left at the acute angle on either side with courses, the beds of which are worked as if for part of a true elliptical arch. This is

[25] Weale. London.

believed by some to be a readier method of completing the work than by following uniformly through the arch the true spiral lines of which it should consist. Some bridges were constructed on the Bolton and Preston Railway in the compounded manner here referred to, and were described in a Paper read before the Institution of Civil Engineers in 1842.

In the construction of brick or stone bridges for railways, much work may be saved by adopting (where allowed) wooden posts and rails instead of solid parapets. The parapet piers may in this case be built out upon corbels beyond the face of the bridge, and thus the same clear width obtained between parapets, and from 1 to 2 feet of brick-work in thickness be saved throughout the work. This method has been adopted in some designs for brick bridges for railways lately prepared by the writer. A tabulated abstract of the quantities in a few of these may be introduced, in order to show the increasing ratio in which the quantities are augmented by additional height of structure.

TABLE A.

Brick bridges over cuttings; 30 feet wide clear between railings; arches 30 feet span, 1 foot 6 inches thick.

Depth of cutting, or height of bridge. Feet.	Excavation. Cubic yards.	Concrete. Cubic yards.	Brick-work. Cubic yards.	Stone-work. Cubic feet.	Wood-work. Cubic feet.
14	98	60	330	402	42
30	112	100	530	465	124
60	915	180	1730	924	280

These are all of similar design: the comparatively great quantity of stone in the 14-feet is employed in imposts of that material, which are not intended in the others. All the designs are of the plainest character, and all the sections are of studied economy in quantity of material.

The following Table, compiled from other designs of the same series, will illustrate not only the similar increasing ratio for bridges in embankments, but also the greater quantity of material required for bridges in embankments than for those in cuttings.

TABLE B.

Brick bridges in embankments; 30 feet wide clear between railings; arches 30 feet span, 1 foot 10½ inches thick.

Height of embankment or bridge. Feet.	Excavation. Cubic yards.	Concrete. Cubic yards.	Brick-work. Cubic yards.	Stone-work. Cubic feet.
19	158	80	405	478
30	278	140	545	395
50	314	157	2290	682

The comparatively larger quantity of stone stated for the 19-feet bridge was required for coping to wing walls, while the other bridges are without such walls, and cut into the bank, which is trimmed around them. A tunnel bridge, with an arch 2′ 3″ thick, in a 40-feet embankment (slopes $1\frac{1}{2}$ to 1), contains 295 yards of excavation, 148 yards of concrete, 751 yards of brick-work, and 653 feet of stone-work.

An approximation to the ratio in which the quantities increase for oblique bridges, and for various angles of obliquity, may be derived from the following abstract of quantities for other designs in the same series.

TABLE C.

Brick bridges in embankments, at various angles of obliquity; 30 feet wide clear between railings; arches 30 feet span, 1 foot 10½ inches thick.

Height of embankment or bridge. Feet.	Angle of obliquity.	Brick-work. Cubic yards.	Stone-work. Cubic feet.
30	80°	1122	414
,,	60°	1198	860
40	80°	2000	766
,,	60°	2394	792
,,	40°	2598	1017
,,	30°	3336	1227
50	80°	2348	727
50	60°	2616	1184

All the arches, where height admitted, are semicircular, and of 30 feet span. The piers are in all cases, where practicable, lightened by arched openings in

the width of the bridge. Two courses of footings are provided for. The arches in most cases spring plain from the pier, without stone or other imposts projecting either on the side or face of the pier.

Tunnels.—Among the costly and laborious works of a railway, its tunnels occupy the first place. Like mining, and all other subterranean operations, the construction of a tunnel can be but little aided by mechanical appliances; it chiefly requires hard manual labour, exercised under circumstances which do not admit of that thorough superintendence which promotes economy, and, moreover, liable to unforeseen interruptions, of surmounting which neither the manner nor the expense can be predetermined. Thus the Kilsby tunnel, on the London and Birmingham Railway, was estimated to cost about £40 per yard lineal; whereas its actual cost was £130 for the same length, owing to its intersecting a quicksand, which the trial borings had escaped. Thus a vast expense was necessarily incurred in setting up and working pumping machinery in order to dry the sand. The pumps brought up nearly 2000 gallons per minute, and were working during a period of nine months. The quicksand extended over a length of about 450 yards of the tunnel. The Box tunnel, on the Great Western Railway, excavated through oolite rock, and being lined with masonry only through a portion of its length, cost upwards of £100 per lineal yard. The Bletchingley tunnel, on the South Eastern Railway, cost £72 per lineal yard; and the Saltwood tunnel, on the same line of railway, cost £118 per lineal yard. This greater cost in the latter work was occasioned by the great body of water in the lower green sand which the tunnel intersects.[26]

The method of proceeding with tunnelling depends mainly upon the kind of material to be excavated. This having been generally ascertained by borings and trial shafts, the work is commenced by sinking the working shafts, which must be sufficiently capacious to admit readily of lowering men and materials, raising the material excavated, fixing pumps, and also for starting the heading of the intended tunnel when the required depth is reached. Besides the trial and working shafts, air-shafts are sunk for the purpose of effecting ventilation in the works below.

The working shafts are made cylindrical, and from 8 to 10 feet internal

[26] The description given of the construction and cost of the two tunnels on the South Eastern Railway, by Mr. Simms, in his treatise on 'Practical Tunnelling,' is most complete and instructive.

diameter: 9 feet is a favourite dimension. They are of brick-work, usually 9 inches thick, and carried up 8 or 10 feet above the surface of the ground, finished with stone coping. These, and all other shafts, rest upon curbs of cast iron, fitted into the crown of the tunnel, and forming a level base for the shaft. The air-shafts are of similar thickness and form, but usually about 3 feet internal diameter. They should not be allowed to be sunk near to the working shaft, or at a less distance than 50 yards from it. All the shafts are, of course, sunk on the centre line of the intended tunnel. In the Bletchingley tunnel, the trial shafts, 6 feet diameter in the clear, 9 inches thick, and 35½ yards deep, cost £6 per yard down through the Weald clay. A similar shaft in the Saltwood tunnel, 25 yards deep, cost £4. 15*s.* per yard down, in the lower green sand. Horse-gins are usually employed in raising and lowering the materials, &c., and also in drawing the water up the shafts, unless large pumps be used and worked by steam power. Mr. Simms calculated the expense of horse labour thus exercised at 2¾*d.* per ton lifted 100 feet high, and including the boy to drive the horse.

The number of working shafts will depend chiefly upon the rate of speed with which the work is required to be accomplished. With plenty of men, horses, materials, and plant, the work is much facilitated by sinking extra shafts, and will usually well repay their cost. The Watford tunnel, 75 chains in length, on the London and Birmingham Railway, was specified to be worked with six shafts, not less than 8 feet diameter within the brick-work, and 9 inches thick; the brick-work moulded to fit the circumference of the shaft, and laid in two half-brick rings; an air-shaft at a distance of 50 yards on each side of each working shaft, and not less than 3 feet 6 inches diameter inside; the arch and side walls of the tunnel, usually two bricks thick, and the invert, one and a half-brick, except in places where the stratum passed through seemed to require an increased, or admit a diminished thickness. The form of the top of the tunnel is nearly semicircular, supported by curved side walls standing on stone footings or skew backs, which rest on the invert forming the base of the tunnel. The ends of the tunnel are formed with wing walls. The brick-work at the ends of the tunnel is bound by wrought iron rods 100 feet long, secured at each end in a cast iron rim or plate built into the brick-work.

The Northchurch tunnel, which is 16 chains in length, on the same line of railway, was worked with two shafts, each 9 feet diameter. In the con-

struction of this tunnel, a heading was driven, 4 feet wide, and 5 feet high, throughout the entire length of the tunnel, and between two shafts sunk for this purpose, one near each end of it. It was specified that this heading should be driven through before any part of the tunnel was commenced, and supported and kept open during the execution of the entire work by sufficient timbering.

In commencing the works of the Saltwood tunnel, already referred to, great difficulty was encountered from the great quantity of water in the lower green sand which the tunnel intersects. The course adopted was to make a heading or adit quite through the hill on a level with the bottom of the tunnel, in which the water was collected and drained off. The size of this, and also of the Bletchingley tunnel, is 24 feet wide at the broadest part, 30 feet including the side walls; 25 feet high in the clear, 30 feet including the invert and top arch, or 21 feet clear above level of rails. The brick-work in top arch and walls varied from two and a half to four bricks in thickness; the invert three bricks thick.

When water occurs in the sinking of the shafts or the building of the tunnel, the back of the brick-work should be well lined with puddle, and Roman or metallic cement substituted for mortar. The whole of the Kilsby tunnel, on the London and Birmingham Railway, was built in either Roman or metallic cement, and the thickness of the brick-work is chiefly 27 inches. This tunnel is about 2423 yards long, and its length is divided by two ventilating shafts, cylindrical, and 60 feet in diameter. These shafts are 3 feet thick in brick-work, laid in Roman cement throughout. They intersect the line of the tunnel, and form curved recesses by that portion of their circumference which extends beyond the width of the tunnel on either side. These shafts were built from the top downwards, by excavating for small portions at a time, from 6 to 12 feet in length, and 10 feet deep.

The Box tunnel, on the Great Western Railway, intersects oolite rock, forest marble, and lias marl, with fullers' earth. Eleven principal shafts, generally 25 feet in diameter, and four intermediate shafts, 12 feet 6 inches, were sunk for the purpose of carrying on the works of this tunnel, the entire length of which is 3123 yards, or a little more than $1\frac{3}{4}$ miles. The section of the tunnel is designed to be 27 feet 6 inches wide at springing of invert, and 30 feet wide at a height of 7 feet 3 inches above this; clear height above rails 25 feet. As a great portion of the tunnel is constructed by mere excavation,

and without masonry, these dimensions are, in some cases, departed from, in order to clear away loose portions of the stone and secure solid surfaces. Where brick-work is used, the sides are seven half-brick rings in thickness, the arch six, and the invert four. During the construction, the constant flow of water into the works from the numerous fissures in the rock, compelled pumping on a most expensive scale to be adopted. From November, 1837, to July, 1838, the works were suspended, the water having gained so completely over the steam pump then employed, that the portion of the tunnel then completed was filled with water, as also a height of 56 feet in the shafts. A second pump, worked by a steam engine of 50 horse-power, was applied, and enabled the works to be resumed.

When the working shafts are sunk sufficiently deep, a narrow heading is excavated, from 6 to 12 feet in length, 3 or 4 feet wide, and high enough for a man to work in. The top of this heading should be so much above the intended soffit of the tunnel-arch as to admit the thickness of the brick-work, besides the bars of timber and boarding by which the roof of the heading is supported, and also allowing several inches for the settlement of the timber, which always occurs as the excavation is proceeded with, and before the brick-work can be got in.

This allowance is of the utmost importance, as without it the brick-work will, when the settlement occurs, be forced down, and can only be raised to its proper level by removing the superincumbent earth piecemeal, and at great cost. The bars, and poling and packing boards, are introduced in the most convenient manner, according to the nature of soil excavated and the degree in which it requires support, or may be safely left unsupported.

The heading is extended on either side by cutting first narrow gaps horizontally, or rather dipping downwards in directions following the intended form of the tunnel-arch. Into these gaps crown bars are laid lengthwise, and supported upon props; and poling boards are put in between them, to retain the earth at the sides of the excavation, when extended. When the heading has thus been widened by excavating right and left, and a sufficient length cleared, the centerings are fixed, and the brick-work is commenced. As this proceeds the earth is carefully rammed behind it, and all vacancies filled up, to prevent any subsequent settlement of the surrounding earth upon it. The crown bars which were inserted in the heading, and always during the excavations, are not always removed. If they can be drawn forward as the heading

advances, without disturbing the adjacent ground, and the spaces filled up with broken stone, or other suitable material, no objection can arise; but otherwise they should be allowed to remain, and be built in. The whole of the operations require carefully regulating, so that none of them shall advance too rapidly for those which follow. The contractors are therefore usually restricted to carry the excavation not more than 6 or 8 feet in advance of the brick-work, or less, if so directed by the engineer, should any change occur in the strata which he thinks may require such precaution. When the faces of two contiguous excavations approach within about 50 yards of each other, a heading should be driven quite through the intervening ground, and the workings joined before the whole excavation and brick-work are proceeded with.

Experience has proved that the *quality* of the bricks used in tunnel-work is of the utmost importance. If these contain lime on which the weather operates injuriously, the face of the work soon decays, and requires extensive repair or restoration. This was the case with the Beechwood tunnel on the London and Birmingham Railway, which in less than three years was considered to be in an unsafe condition, owing to this cause. The remedy adopted was of the most complete character; it consisted in an entirely new lining of brick-work, 9 inches thick. This tunnel is about 302 yards long, and passes through strata consisting of alternate layers of rock and marl, abounding with springs of water. By judicious arrangement, the lining was completed in forty days. The traffic being diverted to one of the two lines of rails which are laid in the tunnel, and a hoarding erected along the centre, the casing was carried up on one side to the height of 4 ft. 6 in. above the springing. At this point a course of York paving, $4\frac{1}{2}$ inches thick, was bonded into the original work, and the new work was securely attached beneath it with wedges of iron; half-brick toothings were also inserted in chases cut 2 ft. 3 in. apart in the original work. The traffic was then turned into the line on the side thus cased, and the other wall was similarly treated. Bearers were then fixed 6 feet apart over head, and a close flooring laid upon them. Upon each bearer a pair of ribs were raised, and keyed stays and laggings were fixed, and the brick-work, in English bond, brought up on each side simultaneously, leaving a central space 2 ft. 3 in. wide at the crown. A moveable centre of this length was used to close in this space with two half-brick rings. Vertical chases, $4\frac{1}{2}$ inches square, besides those cut for the toothings, were made in the face of the old walls previous to lining. These formed permanent drains, terminating in the culvert beneath the centre of the tunnel.

SECTION IV.

PERMANENT WAY AND CONSTRUCTION.

Under this Section it is proposed to give a general notice of those works which may be considered as constituting properly the railway.

Supposing the level for the intended line to be obtained as far as the height of embankments, the depth of cuttings, and the upper surface of bridges or viaducts under the railway, are concerned, the works will have attained what is called the formation level, and be ready for the construction of the Permanent Way. This comprehends a surface covering of gravel, cinders, or other similar ballasting, in which the sleepers are to be embedded. The sleepers, according as they are laid transversely to the direction of the railway or longitudinally with it, will support chairs, in which the rails will be carried, or will have the rails themselves bolted down at once upon them. This part of the work includes also the contrivances by which a communication is made between one line of rail and another, for the passage of engines and carriages: these contrivances consist of crossings and turn-plates.

For the ballasting, which should usually be from 18 to 24 inches in thickness, several materials may be used, according to the facility of obtaining them in the neighbourhood of the works. Loam may be used for this purpose, but is not so good as other materials. On the Aylesbury Railway a mixture of chalk and flints is used with much success.

The ballasting, 22 inches thick, employed on the Birmingham and Gloucester Railway, and which chiefly intersects strata of marl and lias clay, is of several kinds, viz., burnt clay, burnt marl, rock marl, gravel, sandstone, cinders, and broken lias and oolite stone. On the Bolton and Leigh and Clarence Railways the ballast is entirely of small coal, which answers extremely well. On the Chester and Birkenhead, Chester and Crewe, and other lines, a mixture of sand and broken stone has been employed. On many of the English railways, also on the Dublin and Kingstown, the ballasting consists of gravel and broken limestone, which makes a very superior and binding material. In other cases gravel alone is used, also a mixture of gravel and sand; broken stone alone has been sometimes employed, but is found to be somewhat deficient in the property of binding. Gravel and loamy sand have been used, not in the mixed state, but in two separate layers, the sand upon the gravel. On the London and

Birmingham, and also on many of the Belgian railways, this plan has been adopted with success. On the North Union Railway the ballasting consists of sand, with an upper layer of broken stone, 4 inches in thickness. On the Dublin and Drogheda Railway, as stone was readily procured, the whole surface of the line was pitched transversely with thin stones; upon this a good bed of broken stone was laid for ballast. A similar plan was adopted by Mr. Telford on the Holyhead road.

The foundations for the permanent way are now almost exclusively formed of timber. Originally blocks of stone were used for this purpose: two holes were drilled upon the upper surface of each block to receive wooden pins or trenails; and the cast iron chairs to support the rails were secured by iron spikes driven into these pins. The blocks of stone were from 21 to 24 inches square, and from 10 to 14 inches in thickness. They were embedded in the ballasting, sometimes square with the railway, and at other times diagonally to it. Many objections were experienced against the use of these blocks. Thus,—they offered no security for preserving the gauge of the line: the tendency of the weight passing over the rails being of course to thrust them asunder, the stone blocks yielded to this, except as far as their own weight and the rigidity of the rails themselves offered a resistance. Besides this, it was found that the excessive weight of the blocks disturbed the stability of the bridges and other constructed works. For these reasons timber was selected as a substitute, and has been since used mainly in two ways,—either as cross sleepers, each being wide enough to support the pair of chairs which determine the gauge of the line,—or in the form of longitudinal timbers, to which a rail formed with bottom flanches may be bolted without chairs; these longitudinal timbers being connected by cross ties, halved or dovetailed into the longitudinal timbers. For the cross sleepers, which are required from 7 to 9 feet in length for the 4′ 8½″ gauge, half-round logs of beech, Scotch fir, or larch, are usually found the most convenient. They should be cut from timber averaging 9 to 11 inches in diameter. Figs. 8, 9, 10, and 11, Plate XXIII., show the two forms of construction hereinbefore pointed out, viz., the cross sleepers with chairs, and the longitudinal timbers without them. The latter system, having been selected for its superior stiffness by Mr. Brunel, as being peculiarly applicable to his 7-feet gauge, has become somewhat identified with the 'wide gauge,' but is not by any means peculiar to it, being applied on narrow-gauge lines with chairs and without them. Fig. 8 is a plan of a portion of a double line of railway laid

upon cross sleepers, in which *a a* are the rails, *b b* are the chairs, and *c c* the cross sleepers. Fig. 9 is a longitudinal section, showing sections of the sleepers; the four marked *c* are represented as they have been commonly used, viz., with the cut or flat surface of the timber downwards, and the level space to receive the chairs being adzed upon the upper surface. It has been supposed that by thus placing the sleepers a wide and level bearing has been secured for them. On the South Eastern Railway, however, Mr. Cubitt has introduced an arrangement shown in the three sections marked *d, d, d,* fig. 9. These sleepers are of Baltic fir, cut from square baulks, divided diagonally into four triangular sleepers, and laid with the right angle downwards. These are sometimes contrasted with half-baulks, which present no more bearing surface for the chairs than do these triangular or quarter-baulk sleepers, and yet contain twice the quantity of timber. This comparison is however evidently inapplicable, unless square timber be proposed, which is much more expensive, and less readily attainable, than the rough logs commonly used for cross sleepers. It is said that the triangular sleepers offer advantages in the facility of packing, as the ballast can be consolidated by ramming, without lifting the sleeper or digging around it; and also the apparent disadvantage of its tendency to act as a wedge is denied, on the ground that the inclination of 90° exceeds the limits within which the principle of the wedge obtains. The evident advantage of not requiring to be adzed for the chairs, has been relinquished by Mr. Cubitt, who, for greater exactness, caused two places to be planed on his sleepers for the chairs to bed upon.

The distances at which the cross sleepers are placed apart must be an aliquot part of the lengths of which the rails are made; but this distance cannot exceed 3 feet 9 inches without requiring a much heavier and more expensive section of rail than will be sufficient if an extra sleeper be supplied for each 15 feet length of rail, by which the distance apart will be reduced to 3 feet. In some cases a distance of 2 feet 6 inches is adopted, and indeed the greater economy of frequent sleepers with light rails and small chairs, and the greater steadiness and equality of motion given to the carriages by this arrangement, are now generally admitted.

The construction exhibited in figs. 10 and 11 is that now adopted on the Great Western Railway, and other lines connected with it. A different arrangement was tried upon this line: instead of cross ties, lying flush with the longitudinal timbers, cross beams or transoms of pine timber, 13 inches by

6 inches, were framed beneath the longitudinal sleepers. These transoms were placed at 15 feet apart, and were of sufficient length to embrace the two lines of railway, or the four longitudinal sleepers. Piles of beech timber, about 9 inches in diameter, and 8 feet in length, were driven down into the ground adjoining the transoms, and bolted to them. This plan has been abandoned in favour of that shown on figs. 9, 10, and 11. The longitudinal timbers are 12 by 6 inches, and the cross timbers 6 by 4 inches.

Figs. 1 to 7 represent the sections of seven varieties of rails: of these, that shown in fig. 1, which is known as a double T rail, has been used, with difference of dimensions, on many railways, laid to the 4 feet $8\frac{1}{2}$ inches, or Birmingham gauge. The figure shows exactly that adopted on the Aylesbury Railway.

Fig. 2 shows one of the sections used on the Birmingham and Gloucester Railway, and may be taken as an example of another class, having the bottom web extended laterally and bevelled off at the sides. The entire section is much less in depth than the double T rail.

Fig. 3 is an example of the Great Western, or 'bridge-rail,' adapted for longitudinal sleepers, and bolted to them by bolts passing through its lower webs or flanches.

Fig. 4 shows one of the sections employed upon the Liverpool and Manchester Railway, having the top surface inclined and curved, with a view to correspond with the lip and conical tire of the wheel.

Fig. 5 is a section of the rail used on the London and Croydon Railway, and presents a combination of the T rail with the broad base of the bridge-rail. Like the latter, this rail is adapted to be bolted down upon longitudinal sleepers.

Fig. 6 shows the section of rail employed upon the Brandling Junction Railway, and is similar to that used on the Newcastle and Carlisle, and other lines.

Fig. 7 represents the single T section which has been used on several lines. The figure shows that selected for the Chester and Birkenhead Railway.

The sections 1, 2, 4, and 6 may be secured in the chairs which support them by wooden keys, wedges, or other means; 3 and 4 are, as already described, secured by bolts to longitudinal timbers; and fig. 7 requires a notch on the side, into which a ball key or other projection may be driven from the chair to prevent the rail rising.

Plate XXIV. contains representations of the chairs which have been chiefly used and approved of for supporting the rails.

Figs. 1, 2, 3, and 4 exhibit the chairs introduced by Mr. G. Stephenson, and which are especially adapted for the single **T** rail.

Fig. 1 is a section, and fig. 2 a plan, of one of the intermediate chairs. The novelty in this chair consists in the mode in which the rail is retained in its place, and prevented from rising. The rails are rolled with an angular notch along one side of them. The chair is formed with a cylindrical hole through one of the cheeks, and at such a height that will correspond with the position of the notch in the rail when supported in the chair. Through this hole a small iron ball is introduced; a split key is then driven through a hole in the cheek, which also crosses the groove in which the ball is placed: the ball is thus forced into the notch on the rail, and by this contrivance the latter is effectually confined in its position vertically, and yet permitted to move longitudinally when any alteration takes place in the length of the rail or the position of the chair.

Figs. 3 and 4 show a section and plan of one of the joint chairs, in which the ball apparatus is provided on each side of the chair, so as to act against the two rails. The main web of each rail is turned off at the ends at an angle with its length, so that the webs of each two contiguous rails may be lapped against each other without interrupting the uniform direction of their top tables, which are notched out to meet over the lap. The joint chairs, as will be seen by fig. 4, are placed obliquely to the line of railway.

Fig. 5 shows a section of a wrought iron rail and chair which has been used in America, and is described in the 'Civil Engineer and Architect's Journal.' [27] In this case B is the wrought iron chair, which is simply a rectangular piece of metal, notched on the upper surface to fit the bottom flanch of the rail, and having two bolt-holes formed in it. C C are wrought iron clamping pieces, formed at one end to fit upon the flanch and against the web of the rail. Each of these clamping pieces has a bolt-hole through it, so that when put together, in the manner represented in fig. 5, the sleeper, chair, rail, and clamps, are securely connected by two screwed bolts and nuts.

Fig. 6 shows the ordinary chair used on the London and Birmingham, and other lines, and is one of the simplest and most efficacious designs to be used with the double **T** rails. The space for the rail in this chair is straight on one side, but curved inwards on the other. Into this curved recess the

[27] Vol. i. page 169.

lower flanch of the rail enters; the space then left between the straight cheek of the chair and the other side of the web of the rail is occupied by a wooden key or wedge, which is driven in until the rail becomes firm in the chair. So long as this key retains its place, the rail evidently cannot move sideways so that its lower flanch should escape from its recess in the chair, while the key itself is prevented from starting upwards by the projection of the top flanch of the rail. After dry weather, if the keys shrink so as to become loosened, they are readily replaced by a blow from the mallet. This defect is, however, obviated in a great degree by previously compressing the keys. This has been very successfully done on the South Eastern Railway, under the patent process of Messrs. Ransom and May, a description of which may be usefully quoted from the Minutes of Proceedings of the Institution of Civil Engineers, in March, 1842.[28]

"Mr. May explained that the peculiarity of the system consisted in the fibre of the timber being compressed equally from the circumference to the centre.

"The pieces of wood for the wedges were cut out with parallel sides, and forced by hydraulic presses into tapering moulds: whilst in those moulds they were subjected to the action of heat, applied through the medium of low-pressure steam, and after being allowed to cool they were forced out of the moulds, and so long as they were kept dry would retain their form; but as the operation simply contracted the dimensions of the sap-vessels, without crushing the fibre, the power of capillary attraction was not destroyed, and when driven into the chair, and exposed to moisture, they swelled so as to remain perfectly tight. There was this difference between wedges so compressed and all others,—that a true wedge was formed from a piece of wood cut parallel on all sides, whilst all former modes that he was acquainted with produced not wedges, but parallel pieces.

"The diminution of the bulk of the trenails by the process is from 100 to 63, and of the wedge from 100 to 80. It is found that the wood does not swell until it is placed in a damp situation, as in the sleepers. Even the most solid wood, such as African teak, can be compressed without sustaining injury. Perfectly seasoned timber will not shrink after the process. One of the principal advantages of the compressed trenails is the firmness with which they

[28] Printed in the 'Civil Engineer and Architect's Journal,' vol. v. page 200.

hold into the sleeper. Around the iron spikes generally used, a sheath of rust is formed by the damp sleeper; the shaking of the carriages tends to draw them upwards, and the elasticity of the fibre around the hole in the sleeper being impaired, it is of no use to drive them down again in the same place, and the chairs eventually become loose."

The trenails of oak here referred to were used to fasten the chairs down upon the sleepers: on the Hull and Selby Railway also round trenails were used for the same purpose, being made of a proper size to fit the hole in the chair when driven in, and having a square head left on them, by which the chair was held down. The method of compressing trenails and wedges adopted previously to that used on the South Eastern Railway, was by driving them through steel rings or moulds, either by blows with heavy mallets, or by one blow of the piston of a press.

Figs. 7 and 8 show a chair of somewhat complicated character, invented by Mr. G. W. Buck. The objects which Mr. Buck had in view in designing these chairs are explained by himself as follows:—"However strong the rail may be, a certain amount of deflection between the points of support must result from the gravity of the passing load; therefore, in order that no motion may be communicated to the chair, (which is essential to the maintenance of the road in good order,) the connection between the rail and chair must be such as to allow of the libratory motion arising from deflection, the rail being, nevertheless, firmly fixed upon its seat, incapable of rising therefrom, and prevented from lateral movement: at the same time it should be free to move longitudinally, as much as the expansion and contraction of its length from variation of temperature may demand. All these ends are attained by having the chairs constructed as shown in the Plate." [29]

The chair shown in figs. 7 and 8 is a joint or double chair, to which, however, the intermediate or single chair is exactly similar. The seat for the rail in the chair is convex, being $\frac{3}{16}$ths of an inch higher at D than at E, E, for the purpose of permitting the libratory motion of the rail caused at the moment of the load passing over it. This form, however, is not peculiar to the chair now under notice. That side of the chair which is next to the flanches of the wheels has contact with the rail at only two points, A and B. On the outer side of the chair the rail is confined to its place by a cast iron chock, F, made in a

[29] 'Public Works of Great Britain,' page 46. 1838. J. Weale.

spheroidal form, and touching in a point only at C, about midway between A and B: this chock has a step or foot, G, resting on the seat of the chair, with a fillet, I, fitted into a corresponding groove. A wrought iron key, H, is placed in a mortise, partly in the chock and partly in the chair: thus the chock is wedged against the rail.

Figs. 9 to 13 show the chairs used upon the South Eastern Railway. They are designed with a view to combine lightness with strength, and cast with inclined cavities for the rails, so as to secure the inward inclination of the rails, which it is thought desirable to preserve, in order to resist the thrust of the conical tires of the wheels. In the figures *a a* are the compressed wedges, and *b b* show the heads of the trenails, the mode of compressing which has been already described. Fig. 9 is an elevation of the chair; fig. 10 is an end view, and fig. 12 a plan of a joint chair; and figs. 11 and 13 an end view and plan of an intermediate chair: in fig. 13 the wedge *a* is supposed to be removed.

Figs. 14 and 15 show a form of chair adapted to single T rails, which was formerly adopted on several railways, and may be considered as a less elegant attempt to accomplish the object aimed at in Mr. Stephenson's chair, before described. In this case a cylindrical iron pin was placed in the groove *a*, having its front end bevelled off to correspond with the notch in the rail, and kept in its place by a split key, driven through it and through the chair at *b*.

Figs. 16 and 17 represent a kind of chair used on the Hull and Selby Railway: for this chair two compressed keys of oak, each 7 inches in length, are used, and the chair is held down by four spikes or bolts. This form of rail and chair is evidently adapted either for longitudinal or transverse sleepers, and on the Hull and Selby Railway both these modes of construction are adopted. With the longitudinal bearers, a lighter rail and chair are used than with the transverse bearers. In the former case the rails weigh 55 lbs., being $2\frac{3}{4}$ inches deep, and the latter 63 lbs. per lineal yard, being $3\frac{3}{4}$ inches in depth. The chairs are $2\frac{1}{2}$ inches and $3\frac{3}{4}$ inches deep for each system respectively.

Figs. 18 and 19 show chairs with hollow metal keys or pins, patented by Mr. W. H. Barlow, March 6th, 1844; the object of the patentee being to obtain a degree of elasticity together with strength and lightness. Fig. 18 shows one of these hollow metal keys of an irregular but complete tube form. Fig. 19 shows one of them in which an opening is left throughout its length: in this case, however, the patentee considers it desirable that the edges of the iron should butt together. He also proposed some modifications of these hollow

iron pins to be used for holding the chairs down upon the sleepers, and also for other engineering purposes. It is reported that two miles of the Midland Railway, in the neighbourhood of Rugby, which was laid with these keys, showed a remarkable difference in the steadiness of the road and the quietness of the joint, as compared with that part of the line laid with wood keys.

Figs. 20 and 21 show a peculiar kind of chair and fastening adopted on the great North of England Railway. In this chair only one solid cheek is used. On the other side the chair has only two parallel flanches, marked *c c* on the figures, and which are sufficiently cut away to allow the rail to be introduced into its place: between these flanches a solid block of cast iron, marked *a*, fitted to correspond with the side of the rail, is secured by a key or wedge *b*, which is driven behind it, and through holes formed in the flanches *c c* for that purpose. In spiking the chairs down upon the sleepers it is usual to interpose a layer of felt between the two.

The following Table presents the principal items included under the title of this Section, as adopted on the several railways named in the first column.

Name of Railway.	Gauge. Ft. In.	Width. Ft. In.	Central space between lines. Ft. In.	Cross or longitudinal sleepers.	Sleepers. Length. Ft. In.	Sleepers. Scantling. Inches.	Weight of chairs. lbs.	Distance between supports. Ft. In.	Section of rail similar to fig. in Plate 23.	Weight of rail per lin. yard. lbs.
Arbroath and Forfar	5 6	28 6	6 5	cross	8 6	8 × 4	14 int. 20 joint.	3 0	Fig. 6.	48
Ardrossan and Johnstone	4 8½	32 0	6 0	cross	8 6		18½	3 0	Fig. 1.	
Birmingham & Gloucester	4 8½	30 0	6 0	cross and long^{l}. ties	8 0 ...... 7 2	10 × 5 13 × 6 7 × 3½	10½ int. 24 joint.	2 6	Fig. 2.	56
Brandling Junction	4 8½	24 6	5 2	cross	8 0	8 × 4		3 0	Fig. 6.	
Chester and Birkenhead .	4 9	30 0	6 5	cross	9 0	10 × 5	21 int. 24 joint.		Fig. 7.	56
Chester and Crewe......	4 8¾	30 0	6 5	cross	9 0	10 × 4½	20 int. 24 joint.		Fig. 7.	56
Dublin and Kingstown ..	4 8½	30 0	7 4½	cross and long^{l}. cross ties	6 0 ...... 12 0 apart	7 × 3 12 × 6		3 0	Fig. 1.	45
Durham and Sunderland.	4 8½		4 5	cross	7 0	7 dia.	10 int. 14 joint.	3 0	Fig. 7.	42
Eastern Counties	5 0	30 0	6 5	cross	8 6	10 × 4½		3 0	Fig. 1.	75
Edinburgh and Glasgow .	4 8½	28 0		cross	9 0	10 × 4½			Fig. 1.	75
Great Western	7 0	30 0	6 6	long^{l}. cross ties	....	12 × 6 6 × 4			Fig. 3.	44 to 62
Lancaster and Preston ..	4 8½	30 0	6 5½	cross	9 0	10 × 5	19½ int. 22½ joint.		Fig. 1.	65
Liverpool and Manchester	4 8½	25 7	5 2	cross	8 6	9 × 4½	26	3 0 to 3 9	Fig. 1.	60 & 75
London and Birmingham	4 8½	30 0	6 5	cross	7 0	9 × 5	26½ int. 31 joint.	3 9 to 4 0	Fig. 1.	65 & 75
London and Brighton ..	4 9	24 0	6 5	cross				3 9	Fig. 1.	76
London and Croydon....	4 8½	33 10	6 5	long^{l}. fixed in cross.	...... 9 0	9 × 5 9 × 4½			Fig. 5.	
London & South Western	4 8½	25 0	6 5	cross	9 0	10 × 4½			Fig. 1.	63 & 73
Manchester & Birmingham	4 9	29 0	6 5	cross	9 0	10 × 5			Fig. 7.	65
Manchester and Leeds ..	4 9	30 0	6 5	cross	9 0	11 × 5		3 0	Fig. 7.	56
Midland Counties	4 8½	26 0	6 5	cross	9 0	10 × 5	23½ int. 28 joint.	5 0	Fig. 1.	77
Newcastle and N. Shields	4 8½		5 5	long^{l}. on cross	...... 6 0 apart	12 × 6 12 × 6			Fig. 5.	54½
Northern and Eastern ..	5 0	26 5	6 5	cross	9 0	10 × 5		2 1½ & 3 10½	Fig. 1.	
North Midland	4 8¾		6 5	cross	9 0	10 × 5		2 3 & 2 9	Fig. 7. & Fig. 1.	56 65

Many contrivances have been suggested, and several adopted, for enabling locomotive engines and carriages to be transferred from one line of rails to another. With a view to effect this object readily,—so that on occasion the speed shall require to be only slightly diminished, and, at the same time, to do it safely and effectually,—so that the train shall not be in danger either

of getting off the rails, or of following the wrong line,—various arrangements of moveable rails or crossings, with apparatus to move them, have been tried. The one most generally adopted, which has in many instances entirely supplanted previous plans, but has not yet been abandoned for any more recent, is shown generally on Plate XXV., and in detail on Plate XXVI.

Figures 1, 2, and 3, on Plate XXV., show three combinations of fixed and moveable rails and apparatus, one or other of which combinations is required, according to the purpose intended. Thus, first, if it is necessary to provide simply means for turning a train out of one line into another, the arrangement shown in fig. 1 is adopted. Or, secondly, if it is required that a train on either line of rails may be turned into the other one, and without backing the train, fig. 2 shows the combination which must be used. Or, thirdly, if it is required that a train shall be enabled to alter its position to any one of three lines of railway, the arrangement exhibited in fig. 3 must be selected.

Each of these arrangements is a combination of a number of two distinct forms of apparatus, known as 'the switch' and 'the points;' the former consisting mainly of a moveable rail or 'tongue,' tapered at the end, and adapted to lie close against the ordinary rail, or to move sufficiently far from it to admit the flanges of the wheels between them; and the latter including tapered terminations for the main rails and the crossing rails at the points where they intersect, and also such guard or check-rails in separate pieces as may be useful in keeping the wheels from swerving out of the intended course, and also from injuring the thin points of the intersections.

In the figures on Plate XXV. the switches are uniformly indicated by the letter A, and the crossing points by the letter C. In fig. 3 a peculiar kind of switch is shown, which, from its being adapted to open a communication between three lines, is called a 'three-throw switch:' this is lettered B; and in fig. 2 peculiar crossing points are required, and are lettered D D.

It will be understood, that the only moveable parts of these rails are the 'tongues' of the switches; and to move these, and render them also self-acting, a weighted lever is arranged to act within a cast iron box, called the 'switch box.' The position of this self-acting apparatus is indicated on the figures by the letters S. B.; one of these being required for each single switch, and two for the 'three-throw' switch.

The single crossing, shown at fig. 1, requires two switches, A A, and two crossing points, C C.

The double, or over crossing, shown at fig. 2, requires four switches, A A A A, two common crossing points, C C, and two peculiar crossing points, D D.

The treble crossing, shown at fig. 3, requires one three-throw switch, B, two common switches, A A, and five crossing points, C C C C C.

The details of these parts are given on Plate XXVI., whereon, fig. 1, A is an enlarged plan of a single switch. Fig. 2, B is an enlarged plan of a three-throw switch. Fig. 3, C shows the parts of a common crossing. Fig. 4, D is an enlarged plan of the peculiar crossing points, of which two are required for the double crossing, shown in fig. 2, Plate XXV. The two figs. 5 and 6, marked S. B., give two sectional views of the switch box, with the lever apparatus for moving the tongues of the switches. The figs. 7 to 12 are sectional views of the several kinds of chairs required for a single switch; the letters a, b, c, d, e, and f, on these figures, show the chairs required at the several points, similarly marked on the plan A, fig. 1. These details are adapted for double T rails. The chair a, fig. 7, is similar to the ordinary chairs, but made with two similar cheeks, and sufficiently wide to hold the two rails, with a large wooden key between them. The chairs required at a^1, a^2, a^3, are exactly similar to this, but of various lengths. The chair b is the same as a, but much wider, in order to accommodate the three rails which occur at that point, as shown on the plan. At the point c a peculiar chair is required, shown at fig. 9. The main rail, marked m on the plan, is here stopped, and thinned off, to enable the flanch of the wheel to take either line, according to the position of the switch tongue, without encountering the square end of the rail. The chair c is therefore provided with a strong shoulder, against which the point of the main rail and the check or guard-rail are bolted. The switch tongue or moveable rail extends from the point f (at which it turns) to the point d, where it opens sufficiently wide to admit the flanch of the wheel to run in between it and the main rail, m^1, fig. 1. At the point f a chair is used, shown at fig. 12, to which the switch tongue, $s\,t$, is bolted. The upper part of the chair turns upon the lower part, and is connected by a strong bolt, with countersunk head. At the several points marked d, d^1, d^2, d^3, and d^4, a chair, similar to that shown at fig. 10, is required. The main rail, m^1, is bolted to one cheek of each of these chairs, and the switch tongue marked $s\,t$, in fig. 10, slides over a plain seating formed on the chairs, according to the motion required, and is prevented from opening too wide by a strong cheek formed on each of the chairs. Fig. 11 is a section of a

peculiar chair required at *e* on the plan, fig. 1, in which the main rail, m^1, and the end of the fixed rail, *r*, are secured by wooden keys. The position of the switch tongue, shown in full lines, is that which it has when open, the main line being open, and the crossing not in use. When the switch tongue is brought close against the main rail, m^1, the wheels of a train coming in the direction shown by the single arrow will be received at the point *d* upon the tongue, and thus taken off the main line. The main line, when open in one direction, is also evidently open in the other, without any movement of the tongue. The wheels of a train coming out from the crossing on the rails, *r r*, in the direction shown by the two arrows, are allowed by the construction of the lever apparatus to press the tongue against the main rail, m^1, thus closing the switch without any attention on the part of the switch-man: as soon as the wheels pass off the point *d* of the tongue, it immediately opens by the self-action of the lever apparatus, thus leaving the main line again free for traffic in both directions.

The tongue is moved with a wrought iron rod, marked *z*, which is fixed to the tongue, but passes freely through a hole in the main rail, m^1. The other end of the rod, *z*, is connected by a pin, with a crank marked *c*, in figs. 5 and 6, the shaft, *s*, of which turns in fixed bearings, *b b*, on the sides of the switch box. This crank is also formed to be connected with a rod, *r*, upon which circular weights, *w*, are held; it has also a socket, into which a handle, *h*, fits. This handle is sufficiently long to be conveniently used by the switch-man. When the main line is open, the handle *h* is in the position shown by full lines, being retained by the weights *w*. In order to close the switch, the handle must be forced back into the dotted position, thus throwing the crank round and raising the weights. This is done by the flanches of the wheels when coming out of the crossing; the only operation, therefore, which requires to be performed by the switch-man is the closing of the tongue, in order to throw a train into the crossing. The switch box is supported in a timber frame, sunk level with the ground. The check or guard-rail prevents the wheels pressing too severely against the tongue.

In the crossing, fig. 3, *m r* shows the main rail, and *c r* the crossing rails; at the point *p* the two rails are closely fitted together, the top flanches being notched to correspond, and the webs thinned off: they are accurately planed on the meeting surfaces, and bolted together. Each of the other rails which would

meet at this intersection is turned off at *t t*. The check or guard-rail is to prevent the wheels of carriages on the crossing from knocking against and injuring the tapered point *p*.

The action of the three-throw switch will be understood from the description just given of the single switch; the three-throw requires two levers and apparatus, one of the rods of which, z^1, passes freely through one of the main rails and one of the switch tongues. The main rails are marked *m m*. The rails and tongues which are used by a train entering the crossing in the direction of the arrow are marked *l* and *r*, according as it is required to cross to the left or to the right hand respectively. For this entire apparatus four switch tongues are required, two long, and two short, marked *st*; two connecting rods, marked *r*, are also needed for coupling the tongues, so that they may be moved together. All the tongues turn on the line *c c*.

From the description already given of the single crossing C, fig. 3, the double one D, fig. 4, will be readily understood. Chairs of peculiar forms are of course required for each of these arrangements, and are always supplied together with the bolts, nuts, pins, and keys complete.

In order to change the position of engines and carriages within a more limited space than that required for a crossing, several forms of *turn-plate* or *turn-table* have been adopted. These are usually made circular on plan, so as to turn within a fixed ring, and of sufficient size to contain one carriage only. Turn-tables are sometimes made large enough to turn an engine and tender together: these require a circular rack and pinion.

One of the best constructions of turn-table adapted to a six-wheeled carriage is shown on Plate XXVII., in which fig. 1 is a quarter-plan of the top of the table; fig. 2, a quarter-plan of the moving apparatus and fixed framing, which constitute the base and the casing of the table. Fig. 3 is a cross section of the entire apparatus; fig. 4, an elevation of part of the casing; and fig. 5, a side view of one of the latches by which the moving table is secured in each of its positions: *a a* are solid rails of wrought iron fixed on the lid to correspond with the gauge of the line, and forming two sets of rails or tracks crossing the lid at right angles to each other. The covering plates, *b b*, which form the lid of the table, are of cast iron, corrugated on the upper surface, and resting in fillets formed on the cast iron top framing, *c* and *m*. The lower framing is also of cast iron, formed with arms, *i i*, with a bearing rim, *q q*, and a hollow central boss, *s s*. The upper framing is also perforated in the centre at *u u*. The

moving top framing is supported by resting near the periphery upon eight cast iron conical rollers, which turn upon the bearing rim, *q*, of the lower framing. It is supported at the centre also by bolts passing through the rim, *v*, of a strong wrought centre pin, marked *d*. This pin turns in a gun-metal step, *r*, supported in a socket, *t t*, which is held in the lower framing, *s s*; the interior of this socket, and of the central hole in the top framing, are truly bored to fit the turned surface of the pin *d*. The rollers, *e e*, are held in their places by rods, *ff*, which rods are screwed in a wrought ring, *ww*, and passed through a light framing formed of a ring, *h h*, of flat iron, and of a continuous bar, *g g*, of angle iron. The bar and the ring being bolted together, the ring *w w* fits a shoulder formed on the socket *t t*. The bearing rims *c* and *q* of the upper and lower framings are accurately planed to fit the turned surface of the conical rollers *e e*.

The casing consists of eight segmental pieces, *j j*, bolted together through meeting flanches, *p p*, and bolted also to ears, *o o*, cast on the lower framing. The latch, *k*, is fastened by a pin to a small bracket bolted to the casing. Four of these latches are thus fixed, and are dropped into notches, *l*, fig. 5, to retain the table in each of its positions. A man-hole and lid are provided at *x*, to give access to the interior, for oiling the rollers, &c.

It is evidently essential, that for these turn-tables an unyielding foundation should be secured. For want of this, many tables formed with cast iron framings have failed, and been speedily broken. In high embankments, the requisite solidity can seldom be obtained without constructing a well of brick-work, on the rim of which, and on a central pier, the table is fixed. To obviate this difficulty, tables have been designed, and found to answer well, with centre pins of a much extended length. The periphery of tables thus constructed is supported by strut-bars, which are fixed into a jacket revolving upon the lower part of the long centre pin.

In the description of the crossings, it should have been mentioned, that merely for the purpose of removing carriages or trains out of the main line, a side line of extra rails is commonly provided. This side line will run parallel with the main line, or divergent from it, if the site is more convenient for that direction. Such siding is made to communicate with the main line by a single switch apparatus and one crossing point, in which the other end of the siding rails leads into a carriage or engine-shed, and is there stopped; or the siding rails communicate at both ends with the main line, by two single switches and crossing points. This latter arrangement is the one usually adopted in arranging

sidings into which slow or luggage trains are run temporarily, in order to leave the main line clear for a faster train, which is expected to overtake or to pass the slow train. With this arrangement, the train is enabled to leave the siding, and resume its position upon the main line, without backing out; but a very serious objection exists to this siding communicating at both ends with the main line, for the gaping end of the switch is thus exposed to the trains passing along the main line in one direction; and therefore, to insure safety, every train that passes requires to be stopped, or, at the least, its speed very materially slackened, lest by any accidental cause the switch tongue should be closed, and thus throw the train into the siding, or partly closed, and there clogged, in which case the wheel would meet the end of the tongue, and thus inevitably force the carriage or carriages off the rails altogether. Sidings which communicate with the main line by one switch only, may, on the other hand, be so arranged that trains passing customarily on that main line shall never '*meet* the points,' that is, the end of the switch tongue. In this case the switch is perfectly safe, and requires manual attention only when carriages are to be driven into the siding.

In order to turn an engine and tender together from one line of rails to another, without using the large turn-table which would be required for this purpose, the simple apparatus in use at the Greenwich station may be applied. This consists of two cast iron girders, about 26 feet in length, (according to the total length of engine and tender,) fixed parallel to each other by cross braces, and adapted on the top surface for the wheels in the manner of rails. These girders are supported on four pairs of small rollers, two pairs near the ends, and two pairs near the centre; and these rollers work upon circular rims of metal fixed in the ground or foundation. A winch and pinion are provided at one end of these girders, which, with their framing, are made to revolve within a circular rim, having an internal cog-wheel or rack, into which the pinion is worked by the winch.

If it be desired to reverse the direction of a train, and to avoid the expense of a turn-table, or to serve its purpose temporarily, and there is sufficient space, two short siding lines may be laid in from the main line, diverging from it, but converging towards each, and meeting at a short distance in the manner of the two sides of the letter V, with a piece of straight line continuing from their point of meeting, so that the whole resembles the letter Y. A carriage or train may be turned down one of these sidings, run along the piece of straight line to

clear the switch, and then backed, along the other siding, into the main line, which it enters in the opposite direction to that in which it left it. In order to shift a carriage from one line of rails to another, within a short distance, such as under a station-roof, where no space can be had for a crossing, a traversing platform is sometimes adopted, of sufficient length to hold one carriage, wide enough to have two sets of rails fastened upon it, and being fitted upon traversing rollers, and adapted to move to the one side or the other as desired. This apparatus, however, may be regarded as forming a part of the station fittings, and will therefore be described and illustrated in the Section of this Paper devoted to the description of those works.

The completion of the railway ready for the buildings and locomotive stock, which will form the subject of the concluding Sections of this Paper, to be given at a future period, includes some other matters of a secondary character, but of which the past experience may be usefully quoted with brevity. These are the fencing and drainage of the permanent way, and approach roads crossing the railway over or under bridges; and the construction of level crossings and gates, where the railway and intersecting roads cross each other on a level.

A good permanent fencing for the sides of the line consists of oak posts 4 inches by 6 inches, 8 feet long, and standing 3 feet 6 inches or 4 feet out of the ground, and 9 feet apart from centre to centre. They may be squared above ground, but are better left rough below, if it saves labour and does not waste material. Midway between each two contiguous posts are smaller ones, 3 inches by 6 inches, and only 5 feet long, the lower ends being cut taper, and driven 1 foot 6 inches into the ground; or the intermediate post may be only 3×2 inches, and spiked to the inner side of the rails. The former makes much the best fence, but the mortising is of course expensive in labour. The rails, of which there are four, are also of oak, and are 5 inches deep by $2\frac{1}{2}$ inches wide, mortised and joined in the principal posts, and passing through the minor ones. Or the rails are placed diagonally, in which case they may be $3\frac{1}{2}$ inches square. The principal posts should be bound with iron hooping. Sometimes five or more rails will be required, and the railing to stand 4 feet above the ground: three wooden rails, with two intermediate wires, form a good fence, and one which has been much adopted. A very secure, but comparatively expensive fence, is formed with three rails above, and paled for the lower half of its height. On some of the railways an entire wire fence is employed. This, however, requires a particular class of workmen to fix and to repair it, and a breaking of one of

the wires extends the mischief and the insecurity for a great length, instead of being confined to one spot, as in wooden fences. Quicks should be planted within the fencing.

In the neighbourhood of stations, &c., where a very secure fence is required, an open batten fence is commonly set up. This consists of squared posts standing 9 feet apart, and 9 feet long, being 3 feet in the ground, and standing 6 feet above it, and are 4 inches by 6 inches. Into these posts three rails are mortised: these rails are halves of square timber, 4×4 inches, sawn diagonally and connected into the posts, so that the diagonal of the square is vertical, and stands $1\frac{1}{2}$ inch within the outer side of the post. Upon the outer side of these rails the battens, 3 inches by $1\frac{1}{2}$ inch, are secured 3″ apart in the clear, ranging in height level with the top of the posts, and within 2 inches of the ground. The posts and the battens will thus range flush on the outer side of the fence, and the tops of them should be bevelled off from the centre. To form a close fence, feather-edged boards are used instead of battens; these should be 1 inch thick at one edge, and $\frac{3}{8}$ths of an inch at the other, and made to lap over 2 or $2\frac{1}{2}$ inches.

In districts where stone is abundant, the sides of the line are frequently protected by stone walls built dry, with coping set in mortar, from 4 to 5 feet high, 12″ to 18″ thick at top, 21″ to 27″ at bottom, and battering on both sides.

The drainage of the earth-works of railways has already been described in the first Section, in which also a general account was given of the side ditches. We have now only to notice some of the methods adopted for completing the drainage of the upper surface of the railway. Across the ballasting, gullets are commonly cut, leading the surface water into the side ditches or drains. Besides the side drains, central longitudinal drains are sometimes formed, in cuttings and embankments, of rubble-work or of perforated tiles, and which communicate, by cross drains, from 10 to 25 yards apart, of similar formation, with the open side drains. Where the cuttings are through sand or other unsteady materials, the side drains formed at the base of the cutting are frequently protected by a covering of flags or rough stones. In districts where stone abounds, these drains are sometimes built of stone, the bottom being formed of flags. In deep cuttings, where capacious drains are required, it is sometimes found desirable to build the side drains of brick-work, either left open at top, or covered with flag stone, with openings or cesspools at con-

venient distances, to take off the surface water. A very durable drain is thus secured, and the cost of construction of drains, whether of stone or brick, is partly compensated by the less width of land required, as their sides may of course be formed much steeper than those of an open trench or ditch. The side drains are also, occasionally, formed of circular perforated tiles or tubes of large diameter, or of brick-work of a circular or other culvert form. Semicircular half-brick open drains are used occasionally for the sides of cuttings. Under-ground drains are frequently formed of semicircular perforated tiles, based on rough stones, flagging, or paving tiles.

Throughout the entire length of the railway, four parallel water-courses should be formed, that is, two on each side. The tops of the slopes of the cuttings are protected by a fence and mound, and outside these a field drain is required for the adjacent land. At the feet of the slopes also drains are wanted to receive the water from the banks, and also from the surface of the railway. The bases of the embankments require drains to receive the water from the railway and from the surface of the banks; and also other parallel drains outside the fences, to protect them and the mounds from the drainage of the adjacent land. The surfaces of the slopes, both of cuttings and of embankments, must be drained by open channels, as already described, conducting the surface water into the lower drains. The sizes of the drains must of course be determined by the extent of surface to be drained, and by the quantity of water to be provided for: the slope at which the sides of open trenches may be formed must depend upon the nature of the soil through which they are cut. They will usually stand well at 1 to 1, if through clay or other tenacious stratum. Several, however, are formed at $1\frac{1}{2}$ to 1, and even as flat as $2\frac{1}{2}$ to 1.

The width of land required for a railway will be determined by the following conditions, which will occur in the order there stated. First, the gauge;—Second, number of lines of railway;—Third, intermediate spaces and side spaces;—Fourth, depth of cutting, or height of embankment;—Fifth, inclination of slopes;—and Sixth, width required beyond the base of embankment or top edge of cutting for ditch, fence, and mound.

In the making or altering of common roads approaching bridges built over or under a railway, the maximum rate of inclination is, in this country, at present defined by the Parliamentary Standing Orders, as follows:

"Where the level of any road shall be altered in making any railway, the ascent of any turnpike road shall not be more than 1 foot in 30 feet, and of

any other public carriage road not more than 1 foot in 20 feet, unless a Report from some Officer of the Railway Department of the Board of Trade shall be laid before the Committee on the Bill, recommending that steeper ascents than the above may be allowed, with the reasons and facts upon which such opinion is founded, and the Committee shall report in favour of such recommendation." It is also specified in the same Order "that a good and sufficient fence, of 4 feet high at the least, shall be made on each side of every bridge which shall be erected." A fence which has been deemed "good and sufficient," and been much used, consists of posts 7 feet long, 4 in. × 5 in., standing 4 feet above the ground, and placed 8 feet apart,—with three rails, 3 inches by $1\frac{1}{2}$ inch, mortised into the posts, besides a top rail, $3\frac{1}{2}$ inches square, placed diagonally, and resting in angular notches cut on the tops of the posts. An iron strap, $1\frac{1}{2}$ inch by $\frac{5}{8}$ of an inch thick, passes over the rail and embraces the post for a length downwards of about 18 or 20 inches on each side, and is secured by clout nails or screws. The approach road will require a good metalling on the surface, and well rounded; and the slopes must be efficiently drained in a similar manner to the sides of the railway.

Where crossings of the railway and other roads on the same level are permitted, that part of the railway destined for public traffic must be well paved and drained, and the rails require protection from the wear of such traffic, without in any manner interrupting the space required for the flanges of the wheels of the railway carriages and engines. For this purpose guard-rails are used, as shown on Plate VIII., Sect. 11. According as the intersecting road is a turnpike or public road, or one only required for communicating between fields or farms, a double or a single width of level crossing is provided. For a single carriage-way, not only are the rails fixed between high flanges, but the channel for the traffic across them is also defined by metal guard-plates, sufficiently wide to allow for various widths between the wheels, and having a vertical flange on one side, similar to the construction of the cart-way on swing bridges over docks and basins. Those parts of the side drains of the railway which cross the level crossings are covered up, and receive the discharge from other drains formed along the sides of the road which crosses the railway. The intermediate spaces between the rails, and for the full width of the road which crosses them, are filled up with pitch-paving, laid regularly, and well grouted in. Across all these intersections suitable gates are indispensable; they should be made each in two halves, for the double crossing, and usually shut across

the common road, being opened to the road and shut across the railway only for such brief intervals as the traffic may require, and at such times as it is known that no trains in the ordinary course can reach the gates. For each double crossing two pairs of these gates are required, and the gate-posts must occupy the four angles of a square, so that each pair of gates shall close together, either in the centre of the road or the railway. Each gate should have a semi-circular disc of wood at the swinging end, painted white, so that when closed, a large circle, say of 4 feet diameter, is presented on approaching the gates. For conspicuity by night, and in fogs, coloured lamps should be fixed at the same ends of the gates. The construction of these crossings, and the forms of rails used, are shown in detail on the figures of Plate VIII., published with the Second Section, and already referred to.

The average quantities, *per mile*, of the several items which are involved in the formation of a double line of railway, of the 4 ft. $8\frac{1}{2}$-in. gauge, up to the completion of the permanent way, and exclusive of the stations and buildings, and locomotive and carrying stock, may be computed as follows:

The quantity of excavations in 342 miles of double line of railway (comprised in ten railways) amounted to 35,338,000 cubic yards, giving an average of about 103,330 yards per mile, or 58·71 cubic yards of earth-work for each yard forward of the line. Assuming the width of the formation level to be 10 yards, or 30 feet (which is about the average), with an additional width of 5 yards on each side, for ditches, hedges, &c., the slopes at $1\frac{1}{2}$ base to 1 of height,—and also assuming the whole line to be either in cutting or embankment, of an average depth or height of 11 feet,—we shall require 56·73 cubic yards of earth-work per yard forward of the line. This is sufficiently near to the actual average of 58·71 yards to answer the purpose of this general calculation. The average width of land required will thus be

$$\underset{\text{Central width.}}{30} + \overbrace{16{\cdot}5 + 16{\cdot}5}^{\text{Base of slopes.}} + \overbrace{15 + 15}^{\text{Ditches, \&c.}} = 93 \text{ feet, or } 31 \text{ yards,}$$

which will give about $11\frac{1}{4}$ acres of land per mile. Allowing for severance, &c., this may be assumed at 12 acres.

The quantity of ballasting, 30 feet wide, and 18 inches thick, will equal 5 cubic yards per yard forward, or 8800 cubic yards per mile.

The sleepers, transverse, 8 feet long, and 10 inches by 5 inches, placed 2 feet 6 inches apart, will require 11,733 cubic feet, or 235 loads of timber; or 4224 sleepers per mile.

The chairs required, supposing the rails to be rolled in lengths of 15 feet each, will be 1408 joint chairs, and 7040 intermediate; and their weight, reckoning each joint chair at 20 lbs., and each intermediate chair at 15 lbs., will be 12 tons 11 cwt. 1 qr. 20 lbs., and 47 tons 2 cwt. 3 qrs. 12 lbs., respectively, or 59 tons 14 cwt. 1 qr. 4 lbs. together.

The rails, assuming their weight at 56 lbs. per yard, will weigh 176 tons,—1408 lengths being required.

If two oak trenails and two iron spikes be required for each chair, 16,896 of each will be wanted per mile, with 8448 wooden keys for fixing the rails in the chairs.

If felt be interposed between the chairs and sleepers, and the former be assumed at 10×5 inches bearing surface, 2933 square feet of felt will be required per mile.

The timber in the side fences, formed of posts 8 feet long, 6×4 inches, 9 feet apart, with four rails $5 \times 2\frac{1}{2}$ inches, and intermediate upright stay 3×2 inches, will consume as follows: 1174 posts=1565 cubic feet; 4696 rails=3666 cubic feet; 1174 stays=269 cubic feet; or a total of 110 loads.

Of the masonry, timber, iron, &c., &c., in bridges, viaducts, culverts, drains, retaining walls, &c., scarcely any estimate can be formed. Taking the average of a few cases, the masonry would appear to amount to about 110,000 cubic feet per mile; but in some cases from 30 to 50 per cent. of this quantity is substituted by timber and iron.

SECTION V.

STATIONS, &c.

The several points for consideration in the design and arrangement of railway stations are too various to admit of any very minute classification. In their general features only can any resemblance be recognised, or any rules made applicable. And yet in this department of his vocation the Engineer finds a large demand upon his discretion, and feels that much of the current economy of the line will depend upon the conveniences or inconveniences which his arrangement of the stations, and their several adjuncts, may provide. The nature and magnitude of the traffic likely to occur, and the peculiarities of site and locality for the intended station, involve the main considerations, and must determine most of the details required. The site will be determined by the contiguity of the town or place to be accommodated, facility or economy of purchase, &c.; and, besides these, the question of relative levels arises, and deserves most especial regard. Indeed the commercial value of the stations may be said to be made or marred by the facility or the difficulty of communicating with the adjoining thoroughfares. Whether the station be above or below the neighbouring level, a similar amount of expense and trouble will be incurred in transferring the luggage, and of inconvenience in transferring the passenger traffic. In some cases, as where a railway is permitted to approach a town only upon a viaduct, this great difficulty is necessarily encountered, and must be provided for by the best expedients which are available. If the level of the rails be only about 4 feet above that of the approach road, the difference is readily made up by steps for the passengers, while it offers convenience in transferring the luggage from the platform direct into carts and waggons. A few additional feet beyond this may be accommodated by extra steps, and by

employing 'shoots' or troughs inclined from the one level to the other; but if the merchandise usually carried be of a bulky and weighty character, the goods department is preferably removed to such a distance that an ascending approach road may be formed. Any difference of levels may be accommodated by this expedient, provided such a length of road can be obtained as will allow the ascent by an easy gradient; but as the goods department is in such cases necessarily removed farther from the town, and from the passenger department, other inconveniences arise which it is very desirable to obviate. Where such approaches cannot be had, and the entire difference of levels must be provided for in a very limited space, it becomes necessary to adopt some mechanical means of raising and lowering the goods, and to provide stairs or steps for the passengers. An example of the kind of hoisting machinery which may be used in such cases will be found among the accompanying Plates, and hereafter described. The examples of stations which have been selected to illustrate these Papers are such as embrace the leading peculiarities of the buildings:—the arrangement of rails, turn-plates, &c., &c., can be readily described, but would have required many more Plates for their exhibition. The two terminal stations shown on Plates XXVIII. and XXIX. are those erected upon the London and Blackwall Railway, the western end of which is supported on a viaduct, while the eastern is somewhat below the level of the Brunswick Wharf. Plate XXVIII. represents the latter, or Blackwall terminus. Fig. 1 is a general or 'block' plan of the building, and shows the arrangement of the rails. The station is adapted to provide for four lines of way, three of which are shown on fig. 1. On entering the station, the left-hand or 'down' line diverges into two branches, the northern one of which is connected with the main line by a switch, and is intended for the reception of spare carriages. Two turn-plates are fixed on each branch of the down line, and are placed obliquely, there not being sufficient width to place them at right angles. By these turn-plates carriages may be transferred from the main down line to the siding, and *vice versâ*. The switch shown connecting them should have such a tongue as may be usually wholly removed from the main line, and laid in connection with it only while in use; otherwise the serious objection would exist of running the down trains *against* the points of the switch, an arrangement which, as already described under 'Crossings,' is always fraught with danger. The southern or 'up' line runs uninterruptedly until stopped against the building. Fig. 2 is an external elevation of the

building and one of the side walls or screens, the other being omitted for want of room. These walls support one side of the outer bay of roofing, the other ends of the principals being carried upon light iron girders, supported on columns of the same material. The entire roof consists of two bays or spans, each about 28 feet span. Fig. 3 is a plan of the building, the ground floor of which contains a booking office, 63 feet 2 inches long by 30 feet wide, a ladies' waiting-room, 25 feet 8 inches by 17 feet 8 inches, a gentlemen's waiting-room, 19 feet 7½ inches by 17 feet 9 inches, with suitable conveniences, an entrance hall, two rooms for the police, and a spacious staircase leading to the upper floor. The foundation plan of the building is indicated by dotted lines. Figs. 4 and 5 are cross sections of the building. Figs. 6 to 16 inclusive show the roof in detail, which consists of T iron rafters and struts, and round tie and suspension rods. The feet of the rafters are received in cast iron shoes, into which the ends of the tie-rods are also secured with gibs and keys. Angle iron purlins are riveted on the rafters, and are filled with wooden battens to receive the slates. The stationary steam engines by which the down trains are propelled are situated at a short distance from this terminus, and the carriages are detached from the rope while in motion, and with sufficient impetus to carry them forward into the station. The rails ascend towards the station, and thus the carriages in departing descend, by their own gravity, to the point where they are connected to the rope. The arrangements for the trains on this line, although frequently described, and probably well known, are well adapted for carrying on the traffic of a short line of railway worked by stationary power, and deserve a brief description in this place. The line is nearly throughout its entire length carried upon brick arches (as described in Section III.), and without facilities for widening it at the intermediate stations. Hence the carriages destined to accommodate these stations are necessarily stopped on the main lines. The whole line being less than four miles in length, and there being five or more stations in that length, it would evidently involve a tediousness amounting almost to an impracticability to arrest the entire train by stopping the motion of the rope at each of these places. And of course similar delays and infrequency of trains would be occasioned by dispatching the carriage for each station separately, and awaiting its arrival before dispatching the next. The manner in which these objections are obviated is as follows:—The carriages are started in the same order in which the stations are situated; that is, the first carriage is intended to traverse the whole

line, and proceed to the other terminus; the second carriage is intended to stop at the most distant of the intermediate stations; the third carriage at the next station, and so on; the hindermost carriage being intended to proceed the shortest distance, and to stop at the first of the intermediate stations. Each carriage, or set of carriages, intended for each station, being attached to the rope by a peculiar clutch or grip (which will be found hereinafter described), the signal to start the engine at the other end of the line is conveyed by means of the electric telegraph, and the whole train then starts. When approaching the first of the intermediate stations, the guard in attendance on the carriage for that station releases the rope from the grip, and the carriage runs onward, by the momentum acquired, into the station; the carriages being further provided with brakes to be used when necessary. Meanwhile the train has proceeded forward, and when approaching the second station, the carriage for that station is detached in a similar manner. In this way all the carriages for intermediate stations are left as the train proceeds, and those destined for the terminus only arrive there. In returning, the carriages being all standing at their respective stations, are separately connected with the rope (then in a quiescent state), and from each station a signal is passed to the other terminus, by which the engine-man is informed when all the carriages are connected and ready to be started. The starting of the rope, of course, moves all the carriages forward simultaneously, and each arrives at the terminus separately, that from the nearest station coming in first, and the others in succession, and each being disconnected from the rope as it approaches the terminus. It is evident that this system could not be applied without some ready and unerring means of conveying signals rapidly, such as the electric telegraph affords.

Plate XXIX. represents the London terminus of this railway, which is supported on brick arches. The Plate shows the building only adapted for the entrance and departure of passengers. The goods department is conducted at some distance from this building, and contiguous to the Minories, where also the stationary engines for propelling the up trains are situated, the line being laid with a slight descent towards them. Fig. 1 is a front elevation; fig. 2 a longitudinal section, taken on the line A A on the plan; fig. 3 a plan; and fig. 4 a cross section of the building. The entrance hall and booking offices occupy a space 32 feet 4 inches by 31 feet 6 inches, and are lighted by three sky-lights. The waiting hall, 58 feet by 56 feet 8 inches, is divided into a first

and second class by the arrival stairs, which are about 10 feet in width, and divided by short landing-places into three easy flights. One line of rails runs along over the waiting hall and on each side of the arrival stairs, being supported on iron girders carried upon columns, shown on the longitudinal section and on the plan. The railway is terminated by massive abutments of brick-work, which divide the booking offices from the waiting halls. The railway is covered by a wooden roof in two bays or spans, and is also enclosed on the sides with corrugated sheet iron, as far as the Minories station. On arriving at this terminus, the passengers alight from the carriages, and proceed on the platform on either side of the arrival stairs, and then turn to the right or left, and depart down the stairs over the booking offices and on each side of the entrance hall.

Plate XXX. represents a commodious arrangement for a small station, comprehending a booking office 20 feet by 33 feet, two rooms for the superintendents, and separate conveniences for the passengers. The building is on one floor only, and constructed chiefly of wood framed and boarded; the foundation walls and chimneys only being of brick-work. Fig. 1 is an elevation towards the railway; fig. 2 the road elevation, having a convenient portico projecting upon four pairs of wooden columns; fig. 3 is a plan; fig. 4 half a longitudinal section, taken on the line E F on the plan; fig. 5 is a half plan of the framing of the roof; fig. 6, cross section on the line A B on the plan; and fig. 7 another cross section, and taken on the line C D on the plan.

Plate XXXI. shows another station, adapted for a moderate passenger traffic, and having more conveniences than that shown on Plate XXX. It comprises a general waiting-room and booking office, 34 feet 8 inches by 17 feet 2 inches, convenient offices for the passengers, besides lamp and store-room, and a kitchen and sitting-room, with closets for the superintendent, all on the ground floor, and has also four rooms on the upper floor, two of which may be allotted to the superintendent or clerk, and the other two to the use of the porter. In this Plate, fig. 1 is a general plan, to a scale of 32 feet to an inch, and shows the platforms, each 120 feet long and 12 feet wide; fig. 2 is an elevation of the building; fig. 3 a plan; fig. 4 a cross section, showing the station building on one side, and the waiting shed on the other, and the line roofed over between them; fig. 5 is a longitudinal section of the roofing; and fig. 6 a plan of the rooms on the upper floor, the intermediate roofing of the central part being omitted to insert the general plan, fig. 1. Stations similar

to these two last described have been erected on the line of the Northern and Eastern branch of the Eastern Counties Railway.

Plate XXXII. exhibits an arrangement which is applicable to a railway on a viaduct of arches, and such as is adopted on the London and Blackwall Railway, two of the arches being enclosed and roofed over. Fig. 1 is an upper plan; fig. 2 the lower plan; fig. 3 exterior elevation; and of fig. 4, one-half is sectional through the arch, and the other half sectional through the building. The building comprises a pay office and waiting hall, besides four closets in two sets. A flight of stairs projects on each side from the face line of the arches, and serves for the arrival and departure of the passengers, according to the direction of the train.

The remaining figures on Plate XXXII. represent a single-floor station, having a booking office and general waiting-room, 32 feet by 17 feet 3 inches, a parcels office, 22 feet 9 inches by 13 feet 1½ inch, and a ladies' waiting-room, besides conveniences for both sexes. Fig. 5 is a front elevation of the building; fig. 6 a plan; fig. 7 an end elevation; fig. 8 a longitudinal section on the line A B on the plan; and fig. 9 a cross section through the booking office. This station is erected on the line of the Birmingham and Derby Junction Railway, now belonging to the 'Midlands' Company.

The terminus of a long line of railway comprises complete arrangements for carrying on a large passenger and goods traffic; and in its immediate vicinity it is necessary to provide means of repairing, and perhaps of constructing the locomotive engines, besides proper places for containing them, and arrangements for supplying the requisite fuel and water. The buildings may be arranged on the two sides of the space intended for the station, the goods warehouse or station adjoining, if convenient; but the locomotive engine-house should occupy a separate space, and be at some distance from the other buildings, to avoid, as far as possible, the annoyance of the noise, steam, and smell, which necessarily pervade the engine-house, and also the danger of communication in case of fire. The buildings will contain waiting-rooms for passengers, separating the first from the second and other classes, separate conveniences for each sex, booking offices, superintendent's office, store-rooms for lamps, oil, grease, &c., &c., rooms for clerks, porters, &c., and also suitable apartments for supplying refreshments. Around the two sides, or two sides and end, as the case may be, of the interior space enclosed by the buildings, a platform, about 10 or 12 feet wide, is constructed, covered with planking, stone

flags, or asphalte, and about 2 feet 6 inches above the level of the rails, by which facility is given for entering and leaving the carriages, and also for loading the railway trucks with carriages, horses, cattle, sheep, goods, &c. The whole of this interior space is roofed over, and lighted by sky-lights or louvre-lights in the roof. Several examples of iron roofing applicable to stations are illustrated and described in the volumes of the Professional Papers of the Corps of Royal Engineers.

On approaching the station, the two lines of rails diverge from each other, so as to bring them close against the platforms, one of which serves as the departure platform, having booking offices, &c., contiguous to it, and the other as the arrival platform, in the immediate vicinity of which the refreshment rooms are suitably situated. The space between the two lines of rails must be wide enough for three or more spare lines of rails, to hold carriages of all classes, horse boxes, carriage trucks, &c. Access from the main lines to these spare lines is obtained by one, two, or more rows of turn-plates, one of which should be placed across each of the extreme ends of the station, and another intermediate, so that first, second, or third class carriages, may be conveniently introduced at any part of the train. Switches may also be laid connecting these spare lines with the main lines, but they should be of such a kind that the tongues may be wholly removed, except when in use, otherwise the arriving trains will run against the points. The roofing is supported by light iron girders, resting upon iron columns, fixed in rows between the spare lines of rails. The goods warehouses, if adjoining the station, should be kept back from the line formed by the other buildings, so as to allow one or more spare lines between the warehouse and the main line. If this cannot be done, the turn-plates must be fixed upon the main line, which is found objectionable, as they are thus exposed to a constant and most destructive kind of wear.

Plate XXXIII. represents a goods station of considerable extent, having five places for trucks to be run in and out, and being connected with one line of rails and two sidings by means of seventeen turn-plates. A raised platform, 26 feet in width, extends along the centre of the building, and throughout its entire length, being divided by cross partitions into five spaces corresponding with the five loading-places from the turn-plates. In each of these spaces a small crane is erected, and bracket cranes are also fixed outside the building over the doorways and above the upper floor. On the other side of the platform a roadway is made through the building, for the admission of road-carts

and waggons to deliver and receive their loads. Figs. 1 and 2 are side elevations of the building; fig. 3 is a plan; fig. 4 a cross section; and fig. 5 an end elevation.

The most convenient form in which buildings for standing engines are constructed is polygonal. Plate XXXIV. represents a complete arrangement for one having sixteen engine-pits, in each of which two engines may stand, thus affording standing room for thirty-two engines. All the pits are radial from the common centre of one turn-plate, and thus any of the engines may be by one movement of the turn-plate transferred from the pit over which it happens to be standing to either one of the two pits which communicate with the railway. The two entrances from the railway are covered in, forming buildings about 50 feet long and 27 feet wide, and having cast iron tanks above, supported upon girders. These tanks serve as reservoirs for water, to be supplied by the cranes into the tenders outside the building. Fig. 1 is an external elevation; fig. 2 a plan, one-quarter of which is shown above the brick foundations, another quarter over the pits, and showing the position of the columns which support the roof; a third quarter of the plan shows the arrangement of the rafters, and the other the top plan of the roof; fig. 3 is a section of the house, taken on the line A A on the plan.

Plate XXXV. represents a house adapted for the repair as well as the standing of locomotive engines. Fig. 1 is a longitudinal elevation, and fig. 2 a plan of the building; fig. 3 is a longitudinal section on the line A A on the plan; fig. 4 a half end elevation; fig. 5 a cross section on the line C C on the plan; fig. 6 a cross section on the line B B on the plan; figs. 7, 8, and 9, are details of the cap of the chimney, the stack of which is shown, in connection with the elevation (fig. 1), by dotted lines which extend across the plan. This building contains two long pits; also one central pit for the standing of engines to be repaired; a repairing shop, smiths' shop, engine-room, superintendent's office, store, &c. The doors are suspended by rollers, which run on rails fixed over the openings.

The provision of the required quantity of water for supplying the tenders constitutes one of the most important objects to be secured at terminal stations. Along the line, watering stations will suffice at intervals of about 20 miles. In some cases, contiguity to a river, or other natural source of the required supply, will make the arrangements simple, but, if much pumping be necessary, a small steam engine will be found an economical adjunct to the watering

arrangements. The four Plates XXXVI. to XXXIX. represent the details of a complete watering apparatus, including pumps, engine, boilers, &c., as used on the North Midland Railway, and also two varieties of water-cranes. Plate XXXVI. shows a general section and plan of the building and well, and the arrangement of the pumps, engine, tank, &c., &c.; Plate XXXVII. exhibits the pumping apparatus and valve in detail; Plate XXXVIII. contains details of the engine and boilers; and Plate XXXIX. shows a balance water-crane and a bracket water-crane, both kinds being extensively used.

On Plate XXXVI., fig. 1 is a vertical section of the building and well, and elevation of the machinery; and fig. 2 is a plan of the building, well, and machinery. *a* is the well; *b b* the rising mains, supported by cast iron girders, *c c*, resting in recesses in the well; *d* the double-throw pumping gear, fixed on cast iron frames carried upon oak girders, *e e*, resting across the brick-work of the well; *f f* are the pump-rods; *g g* the cranks; *h h* the connecting branches, and *i* the tank supply-pipe; *j* the tank, formed of cast iron plates with flanges, through which bolts are screwed, and iron cement inserted between the flanges. The tank is supported upon cast iron girders, *k k*, which span the building, and rest upon the walls. The tank is strengthened with wrought iron stay-rods, *l l*, fixed by bolts and eyes across the angles: *m* is a valve for admitting the water to descend the pipe *q*, into the lower end of which the pipe *r* is fixed, which is connected with the water-crane adjoining the rails. The valve, *m*, is opened by means of the chain, *p*, lever, *n*, and rod, *s*, and closed by the counterweight, *o*, when the chain is released; *t* is the waste-pipe. The same letters refer to the same parts shown in figs. 1 and 2, Plate XXXVII. Figs. 4 to 12 inclusive exhibit details of the valves, and fig. 13 is a sectional plan, taken on the dotted line *z z*, of the rising main, *b*, and connecting-pipe, *h*. Reverting to Plate XXXVI., *u* is the pump-shaft, *v* the fly-wheel, *w* the crank, *x* the connecting-rod, *y* the steam engine, *z* the steam pipe, and *b o*, *b o* the boilers.

Plate XXXVIII. represents the engine and boilers in detail. The engine is of four horses' power, and of the high-pressure kind. Fig. 1 is a side elevation of the engine, and fig. 2 a plan; fig. 3 shows the front end, and fig. 4 the hinder end; fig. 5 is a longitudinal section of the cylinder, and fig. 6 a cross section through the steam chamber; fig. 7 is a longitudinal section of one of the boilers; fig. 8 a front elevation; fig. 9 a plan; and fig. 10 shows cross sections, one through the fire-bars and safety-valve, and the other in front of it.

Plates XL. and XLI. contain elevation, sections, and details, of a hoisting apparatus employed on the London and Blackwall Railway, chiefly for the purpose of loading the railway trucks with sugar hogsheads. The hoisting station is situated near to the West India Dock warehouses, whence the hogsheads are brought in low trucks, each of which holds two hogsheads. Three of these loaded trucks (from which the horse-shafts are readily removed) are then hoisted upon one of the railway trucks, and thus are transferred to the London end of the line, where they are discharged by means of another hoisting machine. The station shown on Plate XL. is constructed upon eight cast iron columns, marked *a a*, built upon brick foundations, bedded upon concrete: the columns are secured by strong iron holding-down bolts, which pass through iron plates built in the brick foundations. Above the columns a cast iron entablature, *b b*, is fixed, and supports eight girders, marked *c c*, upon the inner lower flanges of which wrought iron rails, *d d*, are bolted, forming six roads for the traversing cranes, (of which one, marked *e*, is shown.) The roofing is supported upon cast iron standards, *i i*, to which are bolted iron shoes, *j j*, for the feet of the principals: *h* is the railway truck, *g g* are the horse trucks, and *f f* are the hogsheads. Fig. 1, Plate XL., is an elevation of one-half of the building, and fig. 2 a section of the other half, both being longitudinal with the railway; fig. 3 is a half section across the line. On Plate XLI., fig. 1 is a side elevation, and fig. 2 a front elevation, of the traversing crane. *a a* are side frames, which were intended to be made of wrought plate iron, but were cast with ribs; *b b* are the axes of the running wheels; and *c* the shaft of the drum, *j*, and the oblique toothed wheel, *i*. The load is raised with a windlass, *g*, having a worm or endless screw, *h*, which works into the wheel, *i*. The crane is made to traverse across the station with a hand-crank, *k*, on the shaft of which is a pinion, *l*, that works into a geared wheel, *m*, on one of the running wheel-shafts, *b*. *d d* are the wheels; *e e* the girders; and *f f* the wrought iron rails, bolted on their lower flanges. The men working the crane stand upon a platform, *q*, supported by stay-rods, *n*, *o*, and *p*, secured to the side frames.

Plate XLI. also contains a few details of sheaves, as applicable for guiding the ropes used on inclines, and with stationary power. Figs. 3, 4, and 5, show the cast iron sheaves first applied on the London and Blackwall Railway: fig. 3 shows an elevation of the sheave, and section of the bearing-box or frame, *b b*, embedded in the ballasting; fig. 4 is a half plan, sectional through a

sheave having an oblique rim, *c*, as adopted for guiding the rope round curves, the higher side being intended to prevent the rope taking the direction of a straight line, as it has a tendency to do, when strained: fig. 5 is a similar half plan, sectional through a sheave, *d*, intended for the straight parts of the railway. The axis, *g*, of the sheave turns in bearings, *e e*, having receptacles for grease with lids, *f f*. Figs. 6, 7, and 8, represent a kind of wooden sheave which has been extensively substituted for the iron ones already described. The sheave is made in two halves, *a a*, secured together by wrought iron rings, *b b*, sunk in the face of the sheave and bolts, *e e*, the heads and nuts of which are also sunk: two iron plates, *c c*, are let into the sheave, and have round holes and key-ways for the axis of the sheave. Figs. 9 to 13 inclusive show two varieties of sheave adopted round curves on the Euston extension of the London and Birmingham Railway. Figs. 9 and 10 are elevation and plan of two small curved iron rollers, the meeting surfaces of which are bevelled: they are supported by a wrought iron standard, having two branches or axes, upon which the rollers are secured by screwed nuts: the surfaces, *b* and *c*, of these rollers form together a continuous curved surface, over which the rope passes, and which, whether the rope presses laterally or vertically, yet revolves, and thus avoids the friction which arises from the rubbing of the rope against the sides of the groove of a sheave which revolves on a horizontal axis only. Figs. 11, 12, and 13, show another contrivance applied on curves, which consists of a common sheave working in a box, placed obliquely, and having attached to it a fixed iron guard or frame, *c c c c*, intended to bear the rope if it escapes from the groove of the sheave: *a* is the sheave, and *b* the box. Figs. 12 and 13 show a dovetailed recess in the sides of the box, within which blocks of hard wood (lignum vitæ, teak, or elm) are fitted. The ends of the axis bear in these blocks, and are greased through a vertical hole bored in the block.

In a former Section reference was made to a substitute for turn-plates, sometimes adopted, in the shape of a traversing platform, made to cross the railway so as to present either of two lines of rails fixed upon it in connection with the fixed rails. Such a contrivance, as applied on the Great Western Railway, at Paddington, is shown in detail on Plates XLII. and XLIII., on which the same letters refer to the same parts.

On Plate XLII., fig. 1 is a plan of the platform, from half of which the top planking is shown removed, for the purpose of exposing the framing, &c., beneath: fig. 2 is a half cross section, and fig. 3 a half cross elevation; figs. 4

and 5 are half sections taken longitudinally with the railway: *a a a a* are the two sets of rails on the platform, and *b b b b* the corresponding fixed rails. The framing of the platform consists of four parallel joists, *d d d d*, fixed in two pairs for the bearings of the running wheels. Upon these joists four others, *c c c c*, are bolted, corresponding with the positions of the rails, and supporting them. Three pairs of longitudinal braces, *f f*, and two diagonal braces, *e e*, are fixed between the main timbers, *c c c c*, and notched down upon the joists, *d d d d*. The platform traverses upon four iron wheels, *i i i i*, the bearings, *l l l l*, of which are fixed to the joists, *d d d d*. These wheels run upon two rails, *h h*, laid beneath, and supported upon timbers, marked *g g*. The motion is guided by four horizontal rollers, *r r r r*, which are attached to the framing of the platform, and work against fixed iron guide-rails, as shown in fig. 10, Plate XLIII. *k k* are two timbers, notched down upon the ends of the rail-joists, *c c c c*. The platform is covered with planking, and made partly removeable, to give access to the wheels and the centre moving apparatus. The running wheels stand partly above the planking, and are protected by sheet iron caps, *j j j j*. The movement of the platform is effected by means of an endless chain, *o o*, connected to the framing of the platform by a fixed hook, *p*, fig. 5, Plate XLII. The chain passes over two grooved pulleys, *m* and *n*, the axes of which are fixed beneath the platform, and the grooves of which have indentations to secure the adhesion of the chain. The chain is guided upon small rollers, *a d*, *a d*, shown at figs. 3, 8, and 9, Plate XLIII. The motion of the pulleys, *m*, *n*, is effected by the gearing shown generally at *q*, fig. 1, Plate XLII., and in detail at figs. 1, 2, and 3, Plate XLIII. Bolted to the pulley, *n*, is a large toothed wheel, *w*, which is worked by a pinion, *x*, on the upper end of the shaft of which is a bevelled wheel, *y*, to which motion is given by the other bevelled wheel, *z*, moved by the winches, *a b*, *a b*. The gearing is supported in a cast iron frame, *a a*, the bed-plate of which, *a c*, embraces the curb adjoining the platform.

On Plate XLIII., figs. 1 and 2 are front and side elevations of the gearing, fig. 1 showing the pulley, *n*, and toothed wheel, *w*, in section: fig. 3 is a plan of the upper and lower gearing; figs. 4 and 5 are elevation and section of one of the running wheels, *i*; figs. 6 and 7 are elevations and section of the pulley, *m*; figs. 8 and 9 are elevation and section of one of the chain pulleys, *a d*; and figs. 10 and 11 are elevation and section of one of the guide-rollers, *r*. In fig. 1, Plate XLII., a latch, *s*, is shown, by which the platform is secured in

its usual position. The latch falls into a notch, *t*, on a fixed plate, turns upon centres at *v*, *v*, and is limited in its movement by the strap, *u*.

Plate XLIV. represents various views of a first class railway carriage. Fig. 1 is a side elevation; fig. 2 is a plan of the under carriage; fig. 3 an end elevation; and fig. 4 a cross section through the body and under carriage. These carriages consist of two main portions, the manufacture of each of which is comparatively distinct from that of the other. These portions are,—the 'under carriage' or 'frame,' including wheels, springs, buffers, brakes, &c.; and the 'body,' which comprehends all above the framing. The one is made with a view chiefly to strength, and requires smiths, joiners, &c.; and the other is adapted to afford comfort and convenience to the passengers, requiring building, stuffing, glazing, painting, &c., &c. The carriage shown on the Plate has three compartments, and holds eighteen passengers. It stands on four wheels, and has a guard's seat at each end. A continuous lower foot-board, *a a*, is fixed along each side of the body, and separate steps, *b b b*, at the doors. The buffer-rods, *c c*, pass through the end bars, *d d*, of the framing, and also through the cross-ties, *e e*, and are formed at the ends, *g g*, with grooves or path , in which the rollers attached to the ends of the buffer-springs, *h h*, move when a pressure on the buffers tends to straighten, and thus elongate, the springs. The springs are strapped at the middle, *i i*, to the ends of the draw-bars, *j j*, *k k* being the hooks by which the carriages are connected together. The springs are thus made available in diminishing the effect of sudden jerks in the draught. *f f* are the side sole-bars, and *l l* the diagonal braces; *m m* are the bearing-springs, and *n n* their carriages, the distances of which may be regulated by screwed bolts, marked *o o*, and of which details are given in a subsequent Plate; *p p* are the axle-guards, and *q q* the axle-boxes. Besides the coupling which connects the carriages by the draw-hooks, *k k*, two reserve side chains, *s s*, are provided with hooks at their extremities: *r* is the wrought iron rod connecting the axle-boxes.

The principal dimensions are as follow: length of frame, 18 feet; width of ditto, 7 feet 6 inches; diameter of wheels, 3 feet; width of ditto, 4½ inches; height from level of rails to under surface of frame (unloaded), 3 feet 10 inches; extreme height of body from rail level (unloaded), 10 feet 5 inches; extreme width of body, 8 feet. The scantlings of the principal parts are as follow: side soles, *ff*, 10 by 4 inches; end soles, *d d*, 10 by 4 inches; cross-ties, *e e*, 7½ by 3 inches; diagonal braces, *l l*, 4½ by 1½ inches; bearing-springs, *m m*,

each thirteen plates, 3 inches by $\frac{5}{16}$ths of an inch; buffer-springs, *h h*, ten plates, 3 inches by $\frac{5}{16}$ths of an inch; buffer-rods, *c c*, $2\frac{3}{4}$ inches diameter, reduced to $1\frac{3}{4}$ inch; draw-bars, *j j*, 2 inches diameter.

Plate XLV. Figs. 1 and 2 show side elevation and plan of second class carriage, the framing of which is precisely similar to that of the first class carriage just described. The body of this second class, however, consists of four compartments, of which three are double-seated, and one single-seated. Four passengers filling one seat, this carriage is adapted to hold twenty-eight persons. Figs. 3, 4, and 5, show an open third class carriage; fig. 3 is a side elevation; fig. 4 a half plan; and fig. 5 an end elevation. The seats are so arranged that the whole space of the carriage is accessible by a single door. Two doors are however provided, one opposite to the other, and situated in the middle of the sides of the carriage. This carriage is adapted to hold about thirty-two persons. The carriages which have lately been established on most of the English railways under an order in Parliament, and hence called 'Parliamentary' or 'Government' carriages, closely resemble the one here shown, in the position of the doors and arrangement of the seats, but differ from it (in accordance with the Parliamentary order) in being wholly enclosed; the sides being continued upwards, and roofed over, and having two or more small glazed openings on each side.

Plate XLVI. contains various details which are common to most of the best made first and second class railway carriages. Figs. 1 and 2 are intended to show plan and longitudinal section of an under carriage frame, with the springs, &c., complete, and to a larger scale than is practicable in showing the entire carriages. In these figures, *a a* are the side sole-bars, *b b* the end sole-bars, *c c* the cross-ties, *d d* the diagonal braces. The side and end sole-bars and braces are secured together by iron knees, *e e*, firmly bolted; the side sole-bars and cross-ties are secured together by iron knees, *n n*, which also are made to serve as guides for the buffer-rods, *f f*, to work in. The ends of the rods are formed with grooves at *g g*, for the rollers at the ends of the buffer-springs, *h h*, to work in. *i i* are the draw-bars, the ends of which have projecting studs that press against the small springs, *j j*, when the draw-bars are in a state of tension. The ends of the small springs, *j j*, are connected to two pairs of rods, *k k*, and the whole of the spring apparatus is secured between two pairs of parallel plates, *l* and *m*. Figs. 3 and 4 show a front and side view of the 'axle-guard,' which is cut from an iron plate, and about $\frac{1}{2}$ or $\frac{5}{8}$ths of an inch in thickness.

The axle-guards are the only means of connecting the carriage framing to the wheels. The wheels are firmly keyed on to the axles, and therefore the axles revolve with the wheels. The axle is prolonged at each end beyond the wheels, forming its journals. A separate metal box adapted to hold grease, and a gun-metal bearing, and made in two parts to admit the journal of the axle, and hence called the 'axle-box,' is fitted at each end of the axle. As the height of the carriage and framing varies according to the load and pressure on the springs, while the height of the axle-box of course remains the same, it is necessary that their connection should admit of this variety of altitude, and of distance between the framing and axle-box. This adjustment is provided by bolting the axle-guards to the framing (on the inside of the side sole-bars), and making grooves in the sides of the axle-box, within which the prongs of the guard may move vertically only. These grooves are shown at *a a*, fig. 8; figs. 5, 6, 7, and 8, being views of one of the axle-boxes; fig. 5 a longitudinal section, showing the axle, and the position of the wheel upon it, the journal, and the gun-metal bearing. *b* is the aperture through which the grease is admitted to the journal; *c c* are small tongues formed on the gun-metal bearings, fitting into corresponding notches in the axle-box, and thus preventing the bearing from shifting on the journal; *s s* are small straps of iron, or spring-ties, by which the springs are secured. The upper and lower parts of the axle-box are connected by means of two strong screwed bolts and nuts, *d d*. The space for grease is usually covered by a lid of sheet iron, turning on a hinge joint, but omitted in the figures to avoid complexity. Fig. 6 is a side elevation of the axle-box, showing a portion of the wheel and axle; fig. 7 is a half front view and half cross section of the axle-box, showing the gun-metal bearing and position of bolts, *d d*; and fig. 8 is a half top plan and half underneath plan of the box.

Fig. 9 shows one of the couplings, known as 'Booth's coupling,' by which the carriages in a train are almost universally connected together. *a a* is a screw, one-half of which is cut with a right, and the other with a left-handed thread, so that one movement of the screw shall either increase or diminish the distance between the tapped sockets, *e e*. These sockets are connected by pins to the links, *f f*, which are put over the hooks, *h h*, of the draw-bars of the carriages. For convenience in turning the screw, *a a*, it is attached at the centre, *b*, by a pin to a lever or stalk, *c*, the weight, *d*, at the end of which tends to keep the screw stationary, and thus prevent any accidental movement of it.

In order to show the coupling complete in one view, the weight, *d*, and stalk, *c*, are shown as if lying horizontally, whereas they naturally assume a vertical position when the coupling is in use.

The braking apparatus, as usually applied to railway carriage wheels, consists of two or four blocks of wood fitted to the periphery of the wheel, and about 15 inches long, 5 inches wide, and 3 inches thick. To these strips of iron are attached at the back, and these strips are slung by iron pins from the sole-bars of the framing. The blocks are so connected by iron rods that a movement which is horizontal, or nearly so, is required in order to force them against the wheels. The apparatus by which this motion is commonly obtained, at command of the guard seated above the carriage, is shown by figs. 10 to 14 inclusive, on Plate XLVI. *a b* are a lever and handle, conveniently situated beside the guard's seat, and keyed to a vertical iron rod, *c*, which turns within an eye or bearing, *d*, fixed by means of two bolts to the upper part of the carriage body. The lower end of this rod is cut with a square-threaded screw, *e*, and its lower point turns in a tapped socket, *h*, which is secured at *i* in the end sole-bar, *j*, of the carriage framing. Another tapped socket, *g*, is also fitted upon this screw, and connected by a pin with two side slings, *f f*, the lower ends of which are pinned to a double-armed or bell-crank lever, *k*, *l*, which is keyed to a shaft, *n*, that turns in an eye, *m*, bolted to the carriage framing. By turning the handle, *b*, so as to raise the rod, *c*, the end, *p*, of this lever will be evidently drawn forwards in an arc, whereof *n* is the centre; and by extending the shaft, *n*, across the framing, two sets of brake-rods may be simultaneously acted upon, so as, if required, to work four brakes at once.

Figs. 15 and 16, Plate XLVI., show a detail of the carriages for the ends of the bearing-springs (as shown on Plates XLIV. and XLV.), which are capable of adjustment, according to the length of the springs. *a* represents the side sole-bar of the carriage framing; *s* the end of the spring; and *c* the iron bracket or carriage, to which the spring is connected by the sling, *d*, which consists of a steel link enclosed in one of leather, and embracing small rollers on the end of the spring and of the carriage. The bearing-plate, *e e*, has two slots, *f f*, working upon the bolts, *g g*, fixed in the sole-bar: *h* is another bolt firmly fixed in the sole-bar, and *i* is a screwed bolt which passes through eyes formed on the bolt, *h*, and on the end of the bearing-plate, *e*. By screwing up the nut upon this bolt, *i*, the bearing-plate, *e*, will be evidently drawn further away from the spring, and *vice versâ*.

Plate XLVII. shows a railway waggon adapted to carry a large quantity of heavy goods. Fig. 1 is a side elevation; fig. 2 a plan of the carriage framing, one half of which is shown above the upper frame; fig. 3 an end elevation; and fig. 4 a half top plan. *a a* are the side sole-bars; *b b* the end sole-bars; *c c* the cross ties, and *d d* the diagonal braces: *e e* are the buffer-rods, and *ff* the rollers on the ends of the buffer-springs, *g g*: *h h* are the draw-bars; and *i i* the hooks for the couplings. The draw-bars are connected at *j j* to the buffer-springs. *k k* show the framing of the body, and *l l*, *m m*, that of the doors, of which there are two at each end of the waggon: *n* and *o* are the iron fastenings to the doors. The doors are continued upwards at *p p*, for additional security to the load. *q q* are the axle-guards, *r r* the axle-boxes, and *s* the connecting-rod between them.

Plate XLVIII. represents a ballast waggon, the height of which may be increased at pleasure by the sides and ends, *a a*, secured by the posts, *b b*, in the staples, *c c*. This waggon is without buffers, and the draw-bars, *d d*, are provided with very simple springs at *e e*. Fig. 1 is a side elevation; fig. 2 a plan; fig. 3 an end elevation; and fig. 4 a half top plan of the waggon.

On Plate XLIX., figs. 1 to 9 inclusive show the details of a very effective brake, applicable to ballast and other waggons, where the action can be had direct by means of a lever. *a* is the lever terminating in a handle, and working within a slot formed on a plate, *b*, having a series of holes, in which a pin is placed, in order to retain the handle in any desired position. When out of use, the handle is kept in its highest position by the spring-stud, *v*, shown at figs. 8 and 9. The other end of the lever is connected at *c*, with a bell-crank lever, having two arms, *s* and *e*. The pin to which the lever, *a*, and the bell-crank lever, are keyed at *c*, turns in two iron plates, *d d*, bolted to the side sole-bar, *t*, of the waggon. The two ends, *s* and *e*, of the bell-crank lever, are pinned to the brake-rods, *ff* and *r p*, the other ends of which are attached by bolts to the iron plates or shoes, *h* and *n*, bolted to the brake-blocks, *i* and *o*, and suspended by slings, *k* and *m*, at *j* and *l*, from the side sole-bars of the carriage. The brake-rods are each made in two pieces, the approaching ends of which are tapped reversely, so that by turning the tapped nuts, *g* and *q*, which connect them, their length may be from time to time increased, to make up for the deficiency occasioned by the wear of the wooden blocks, *i* and *o*, against the wheels. Fig. 1 is a partial view of the waggon; fig. 2 a cross section of the side sole-bar, *t*, with the bell-crank lever and pin, *c*, in connection; fig. 3 is a

separate side view of the bell-crank lever; and fig. 4 is a front view of one of the pins, *s*, showing the separate collar secured to it, after attaching the end of the brake-rod. Fig. 5 is a separate view of the brake-rod, *ff*, showing the block, *i*, and shoe, *h*, in section. Figs. 6 and 7 are separate side and front views of one of the shoes, *n*, with its sling, *m*, and pin, *u*, by which it is secured to the side sole-bar, *t*; and figs. 8 and 9 are side and front views of the handle-plate, *b*, with its spring-stud, &c. Figs. 10, 11, and 12, show a simpler and less effective form of brake, applicable to a similar class of railway waggons, and which acts only on one wheel. The same letters in these figures refer to similar parts to those described of fig. 1, &c.

Figs. 13 and 14 represent the grip or clutch attached to the two ends of the carriages, &c., used on the London and Blackwall Railway. Fig. 13 is a front view; and fig. 14 a section taken on the line A A on fig. 13. *a* is the end sole-bar, which extends beyond the body of the carriage, and is planked over, the guard standing on this projection in order to have immediate command over the grip and brakes: *b b* are two tongues or forks, not placed in the same plane, but fixed one behind the other; and *c* is a moveable tongue or hook, working between them, and which is thrown back in order to admit the rope between the forks, *b b*, then forcibly pressed upward, so as to secure a firm grip of the rope, and again thrown back, on approaching the stopping-place, so as to release the rope. The moveable tongue, *c*, terminates upwards in a lever or handle, *d*, having a centre at *e*, on the radial lever, *g*, which turns on a fixed centre at *f*. The lever, *g*, has also a pinion on the end of a small lever, *j*, and a pall, *l*, on the end of another lever, *k*, attached to it. This pinion and pall work on the two edges of a fixed curved standard, *i*, one of which is formed with teeth, and the other with a ratchet. When the rope is embraced between the tongues, *b b* and *c*, the lever, *g*, is forced upwards, aided by pressing the handle, *j*, downwards; and when the required force is attained, the pall, *l*, is dropped into the nearest tooth of the ratchet. In order to release the rope it is only necessary to remove the pall, and press the lever, *d*, towards the standard, *i*. The levers, *d* and *j*, are kept in their proper planes by the ties which extend from *f* to *h*.

Figs. 15, 16, and 17, show a contrivance affixed to the ends of railway trucks intended to carry road carriages, for the purpose of receiving the wheels of such carriages. It consists of a metal plate, *b*, turning on centres at *c c*, and supported by a bracket, *f*, bolted at *g* to the end sole-bar: leading from the

plate *b* is an inclined plate, *a*, and both of these having raised edges, the wheels are with certainty conducted to the space intended for them, between ribs of wood bolted to the flooring of the truck. The dotted lines at *d* show the position of the plate or flap, *b*, when not in use.

Many contrivances and combinations have been attempted in the manufacture of wheels for railway carriages. In the early period of railway history, wheels made wholly of cast iron were tried, but found quite unequal to the wear occasioned by high velocities, and the concussions to which they were exposed over new lines, &c. Hence combinations of cast and malleable iron were tried, and, fashioned in a variety of shapes, these materials have ever since been most widely adopted. The boxes or naves are cast, and the arms or spokes, and rim or tire, are of malleable iron. In the ordinary forms the mode of manufacture is this:—the arms, being rolled and properly formed, are arranged in the positions they are intended to occupy in the wheel around a box or mould for the nave, and into which mould cast iron is introduced in a melted state. The attaching of the tire is another operation: the iron, being rolled to the proper section, and cut to the proper length, is next placed in a furnace, and then bent in a mould to the intended circular shape, after which it is shrunk on upon the arms and riveted to them. The finishing operation is the turning of the surface of the tire.

A machine for bending and setting the tires of railway carriage wheels was described in a paper by Mr. J. Woods, read before the Institution of Civil Engineers, in the session of 1841. The abstract of this description may be quoted from the 'Civil Engineer's Journal,'[1] as follows: "The usual mode of bending tire-bars was by means of swages and hammers round a fixed mandril: after being welded, they were stretched on a cast iron block, formed of two semicircular pieces hinged at one point, and wedged apart at the opposite side: the hoops, being heated, were placed on this block, and by repeated blows driven into close contact with the mould. Much difficulty was experienced in thus making up tires for large railway wheels, and the present machine was constructed for facilitating the process. One end of the tire-bar, when heated, is wedged into contact with one of four segments of a circle, of the required diameter, upon a cast iron table, which is caused to revolve slowly; the pressure of a guide-wheel at one side forces the tire-bar to warp round the segments,

[1] Vol. iv. p. 318.

and to form the circular hoop required; its ends, having been previously scarfed, are then welded together. The tire is again thoroughly heated, and placed around the four segments, which slide radially on the table, and are then simultaneously forced outwards by a motion of the centre shaft. The tire, being slightly chilled, and assisted by the swage and hammer, soon adapts itself to the segments, and forms a circular hoop instead of two semicircles irregularly joined at their points of contact, as by the old system: it is then ready for being chucked on the lathe, and bored out before shrinking on the wheel. It is apparent that a machine of this description becomes applicable to tires of any diameter, by having three or four sizes of segments adapted to the table. It is found to diminish the manual labour, and to prepare the tire more accurately than by the usual process."

On Plate L. six varieties of railway wheels are shown. Fig. 1 is an elevation, side view, and section of a wheel, of which the nave or box only is of cast iron: the tire is rolled, and the spokes are formed of iron plate, 4 inches by $\frac{1}{2}$ inch: each spoke consists of a pair of these plates, which meet at the tire, but diverge in curved lines towards the nave, and are by this arrangement intended to afford some elasticity. The plates forming the spokes are continued within the inner circumference of the tire, and secured by screwed bolts and nuts, the heads of the bolts being countersunk on the tire, and turned to lie perfectly flush with it. Fig. 2 shows similar views of another wheel, consisting of one member more than that just described, viz., a separate inner band or tire having a tongue or rib rolled on it. The spokes are formed of rolled iron, of a section resembling the letter T, and are curved so as to present arched surfaces towards the tire. Each adjoining pair of spokes meet in approaching the nave, into which they are fixed in the process of casting it. The arched surfaces of the spokes are formed with grooves, corresponding with the tongue on the inner tire; and both tires and the spokes are secured together by bolts, of which the heads are countersunk and turned off, and the inner ends are riveted through the crown of the arches formed by the spokes. Fig. 3 shows elevation, side view, and section of a wheel having cast iron nave and arms and rolled tire. The arms are of the H section, and cast together with an inner tire, and the two tires are secured together with wrought iron bolts, countersunk on the head, and turned with the tire. Fig. 4 exhibits a wheel, of which the arms are formed of iron plates similar to those shown on fig. 1; but in this wheel they are arranged so that the curvature or bow is transverse to the plane of the

wheel, instead of being parallel to it. The meeting ends of each pair of plates forming the spokes are received between two tongues rolled on the inner circumference of the tire. In the wheels yet described metal only is employed, but in those shown in figs. 5 and 6 a portion of wood is introduced, whereby the quality of elasticity, so desirable in railway wheels, is sought to be obtained. In the wheel shown in fig. 5 the spokes are of wood, and are received in sockets formed in the cast iron nave, and at the outer ends mortised into an inner tire of wood, which is made in segments, and bolted to the rolled iron outer tire. In fig. 6, the bearing surface of the tire is formed of wood, which is fitted in small segments into a groove formed on the tire. The inventor of this wheel, Mr. Dircks, has thus described it.—" The construction of this wheel may be understood by imagining a spoked wheel with a deep channelled tire. The wheel may be made either of cast or wrought iron, it having been ascertained that tire-bars can be rolled to the required pattern. In this channelled tire are inserted blocks of African oak, measuring about four inches by three and a half inches, solidified by filling the pores with unctuous preparations; thereby counteracting the effects of wet by capillary attraction, to which by this means it becomes impervious, and at the same time is not liable to unequal contraction and expansion. The blocks of wood are cut to the requisite form to fit very exactly into the external circular channel of the wheel, with the grain placed vertically throughout, forming a complete facing of wood." There are about from twenty-eight to thirty of these blocks round each wheel, where they are retained in the required position by means of the bolts, as shown in the engraving.

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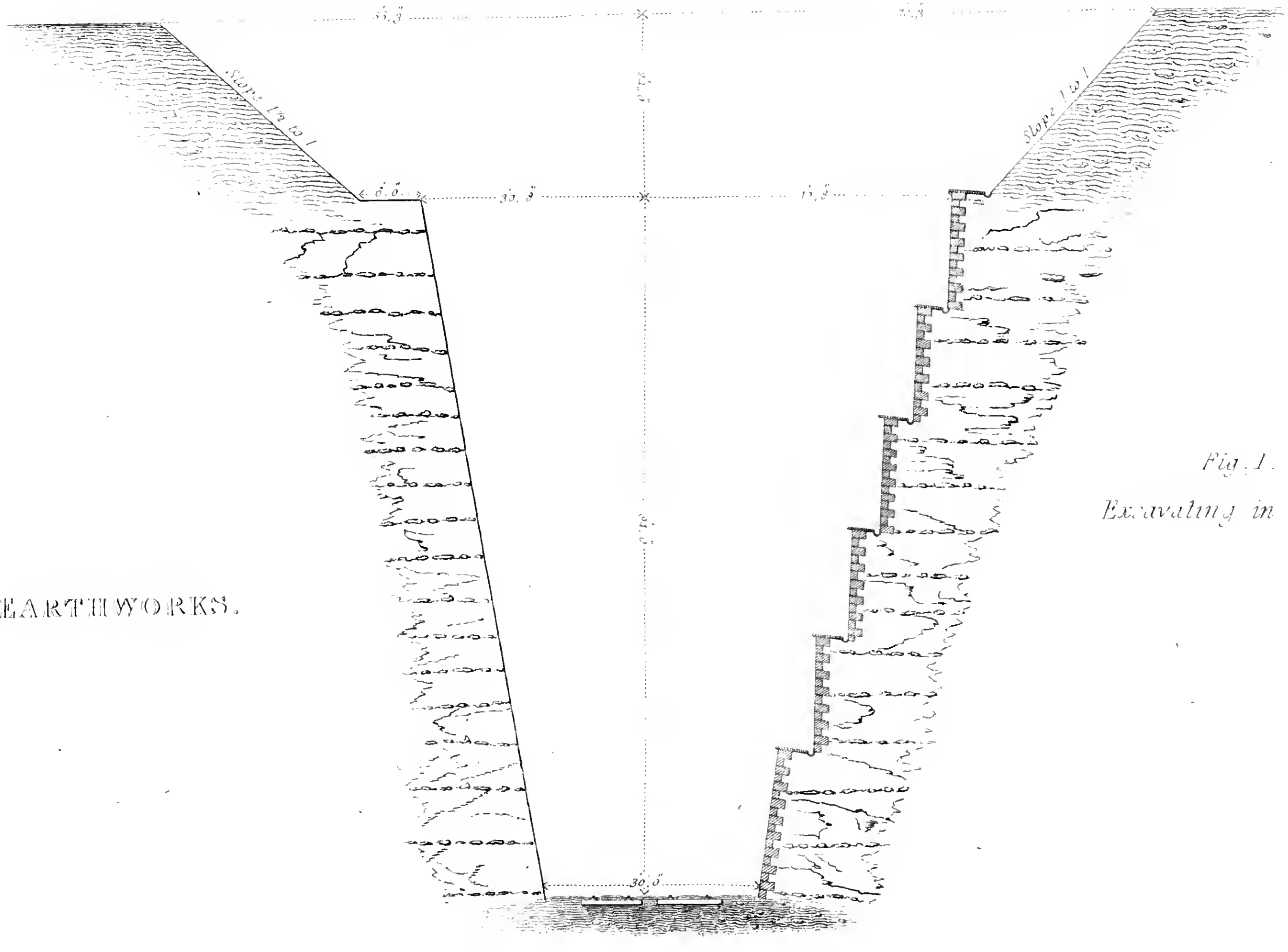
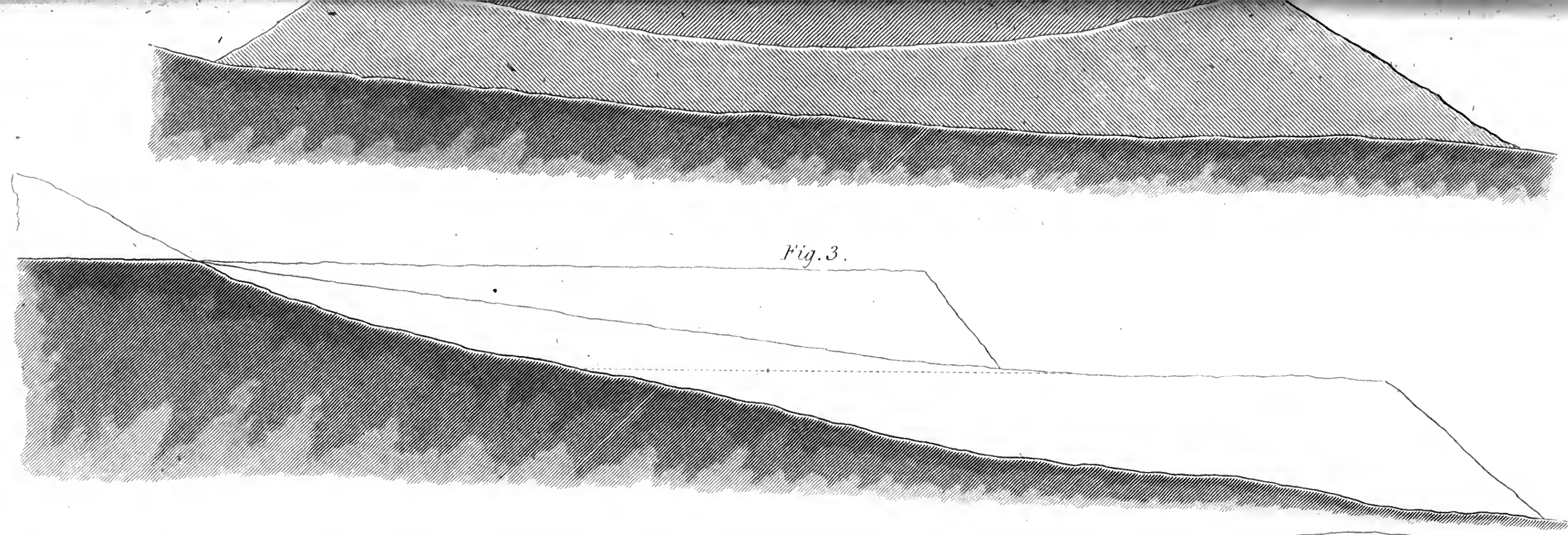


Fig. 1.
Excavating in Chalk

Fig. 2.



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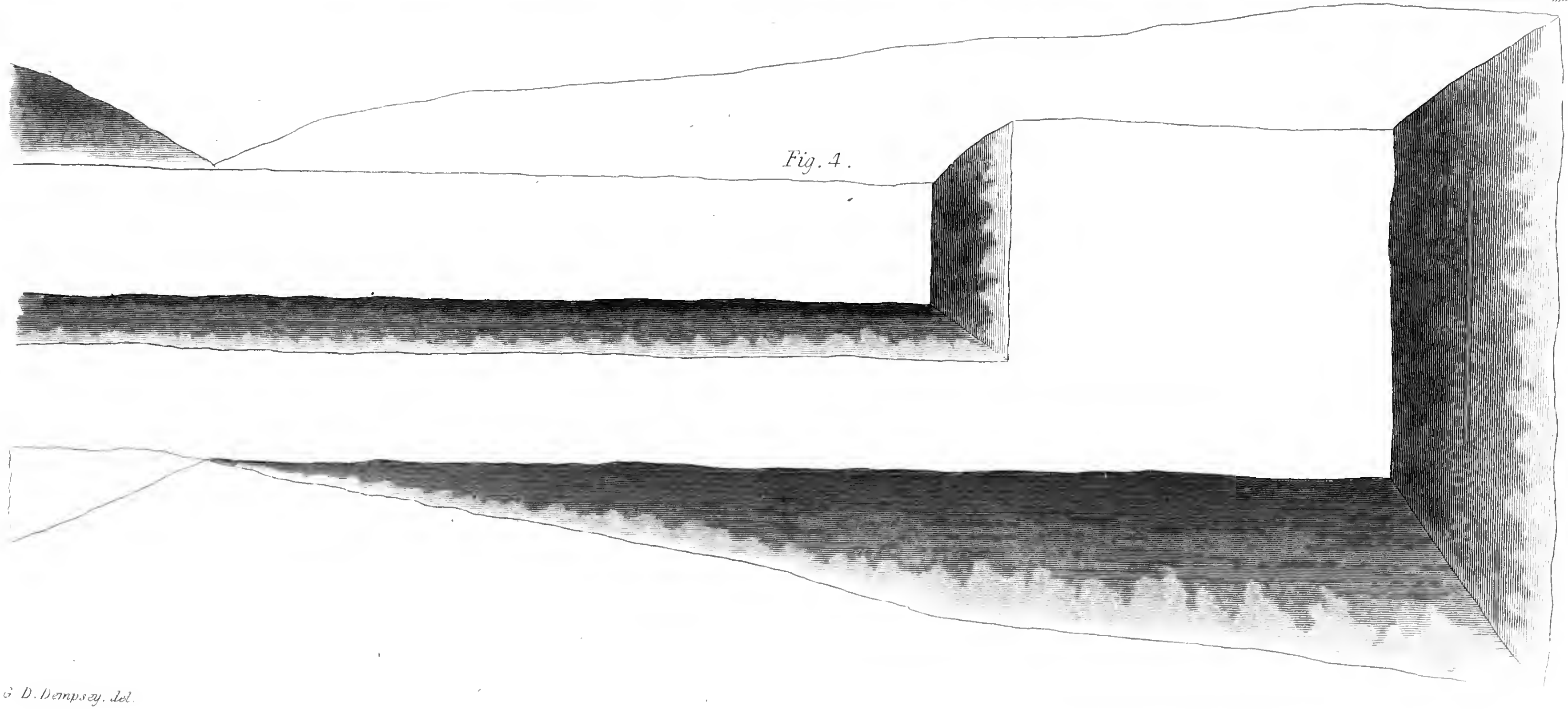

Fig. 4.

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London. John Weale. 59, High Holborn, 1844.

Section of an Embankment.

Fig. 1.

Section of a Cutting.

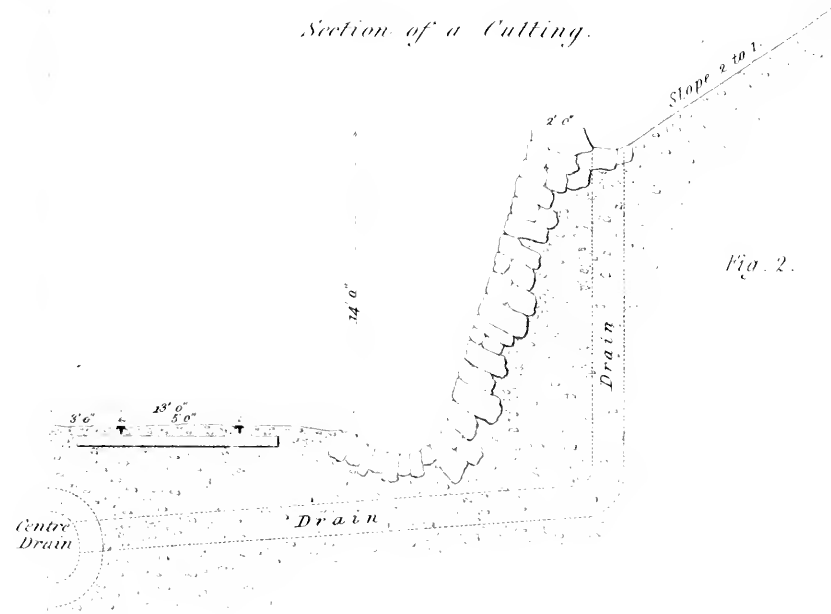
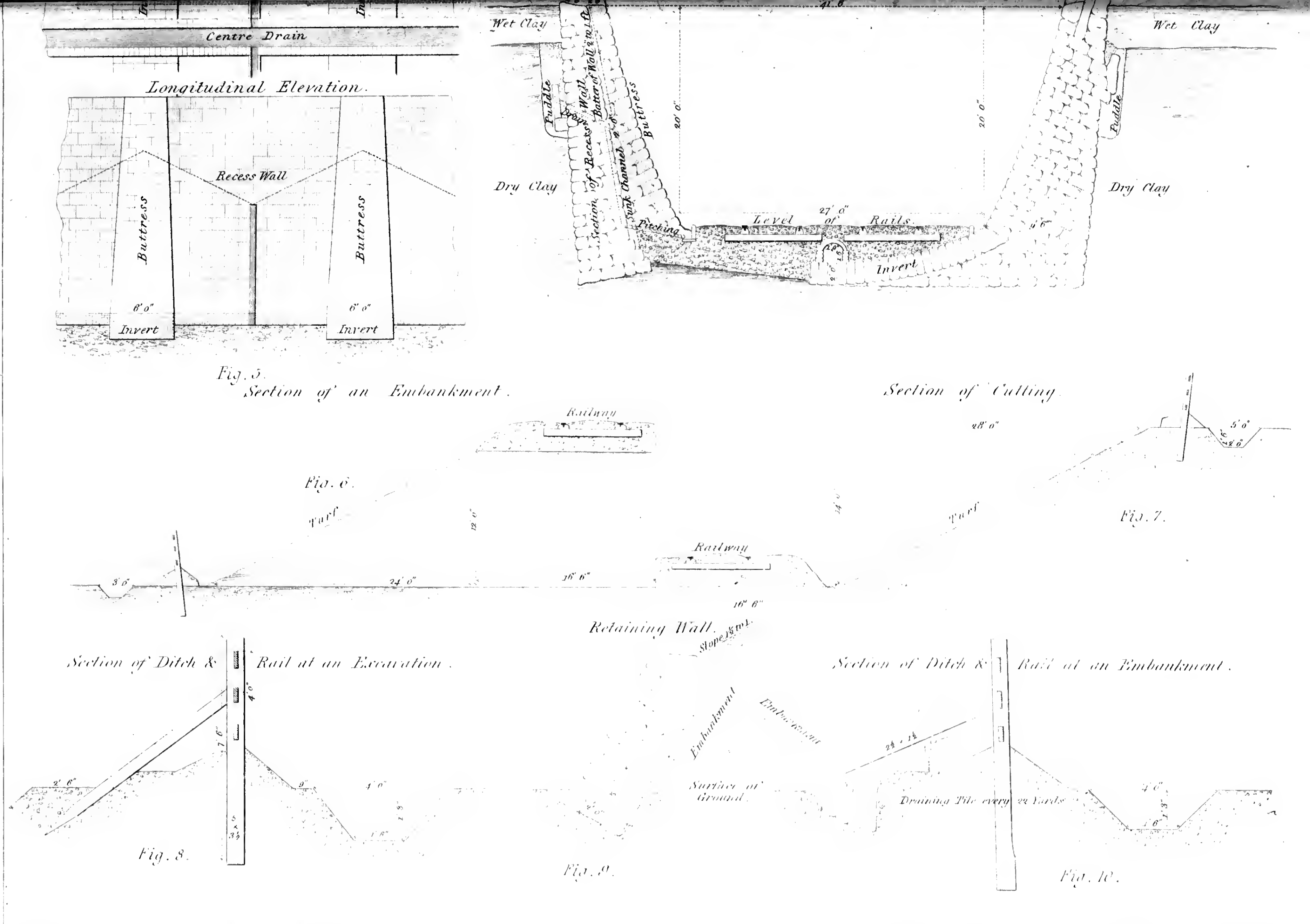


Fig. 2.

Blisworth Cutting
Cross Section.

Fig. 3.



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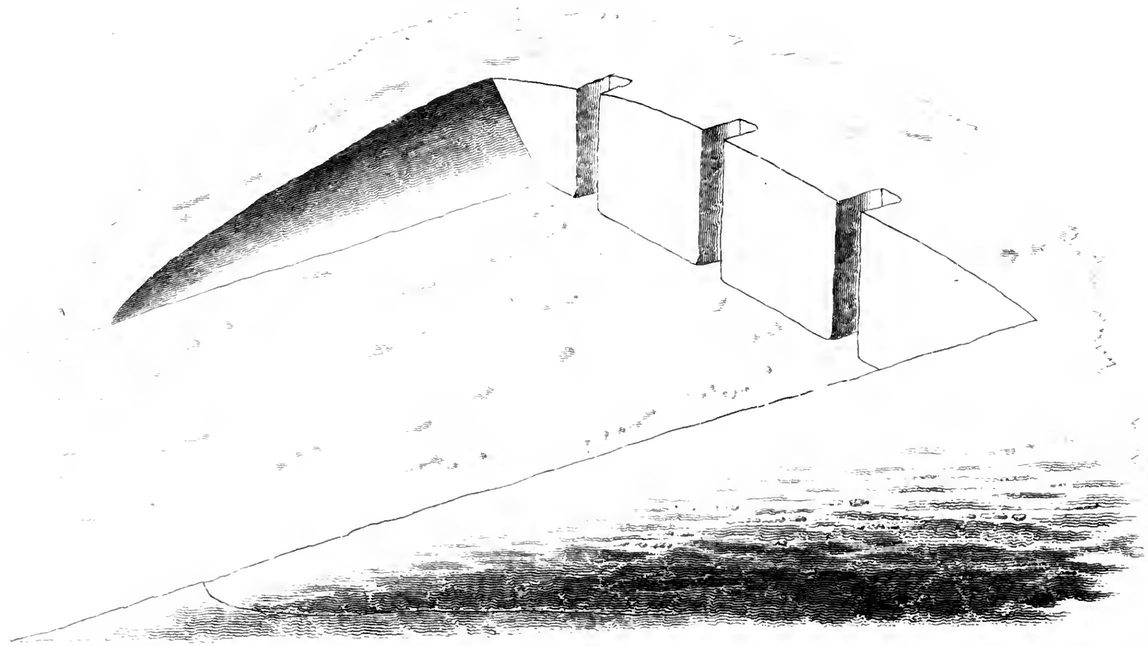

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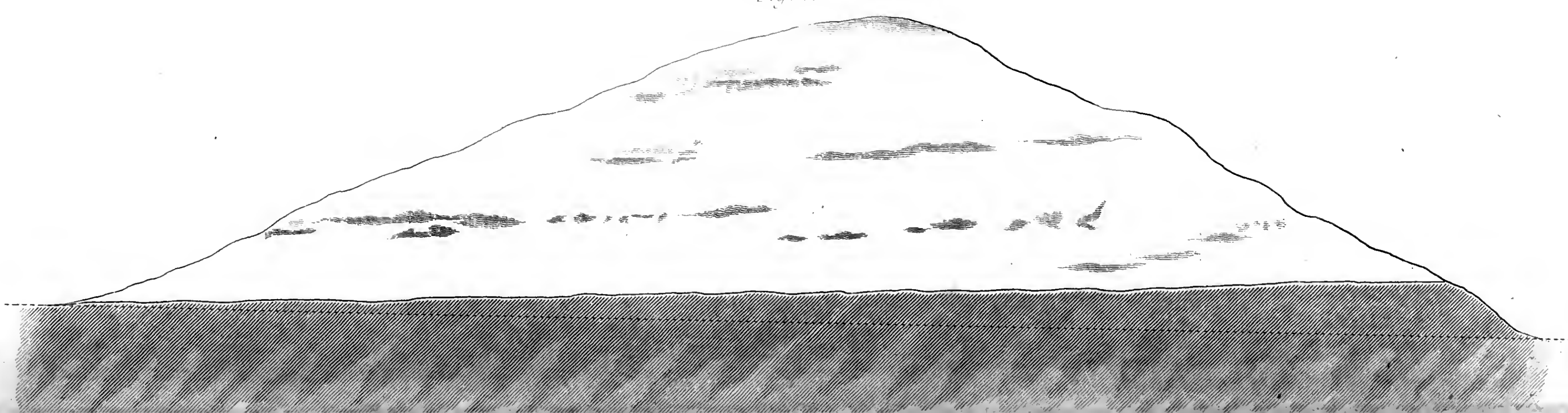

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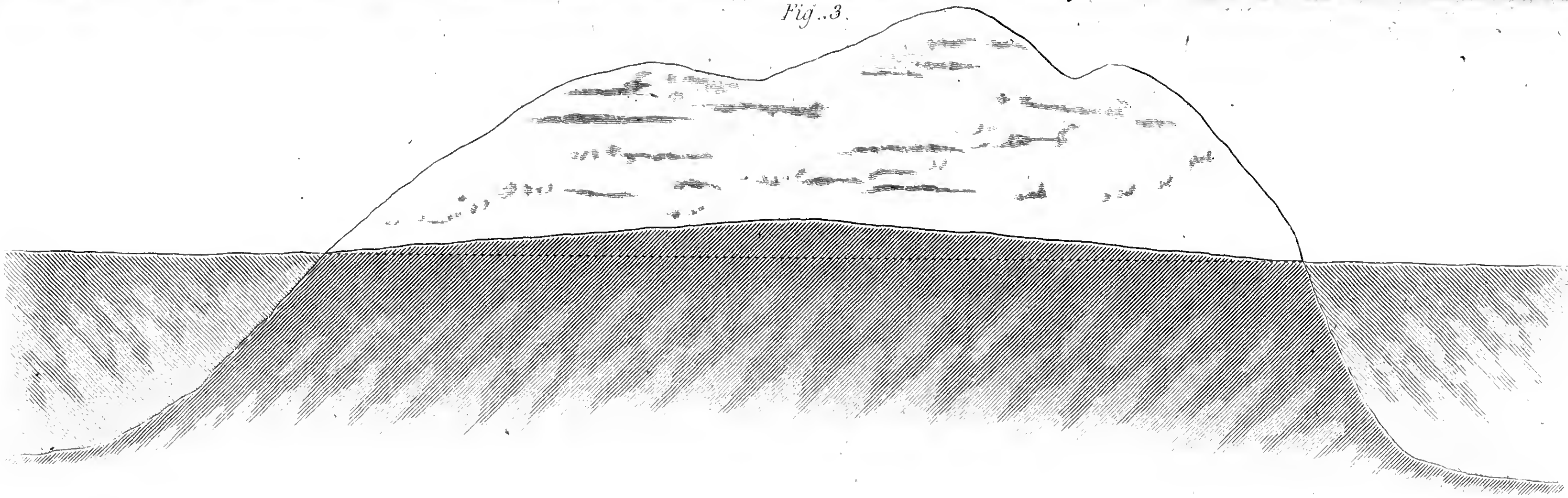

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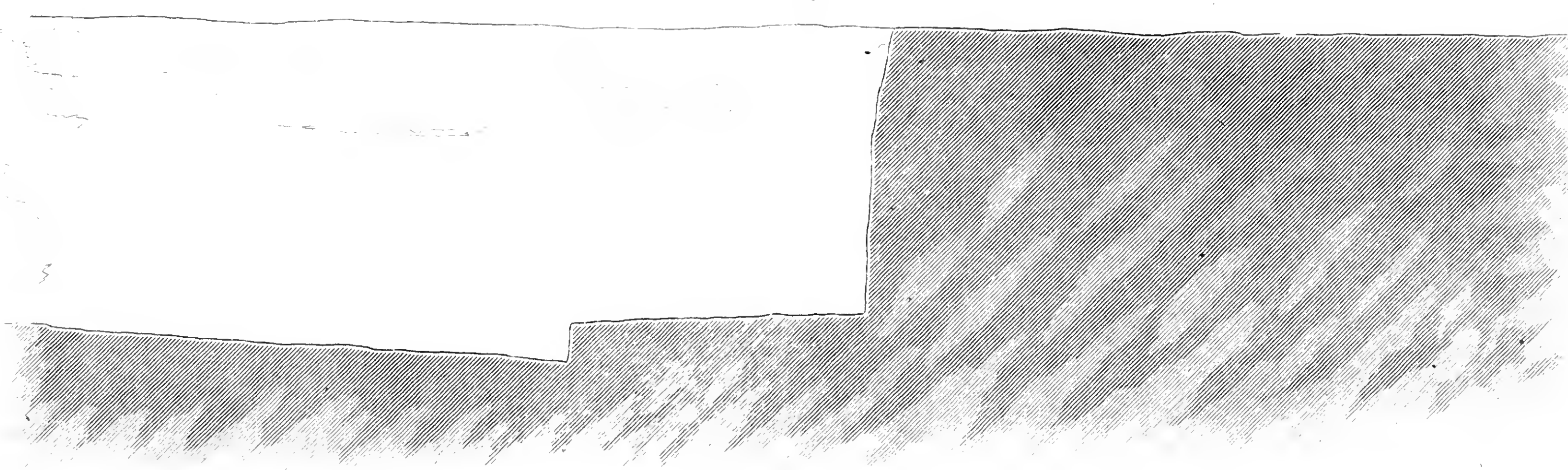

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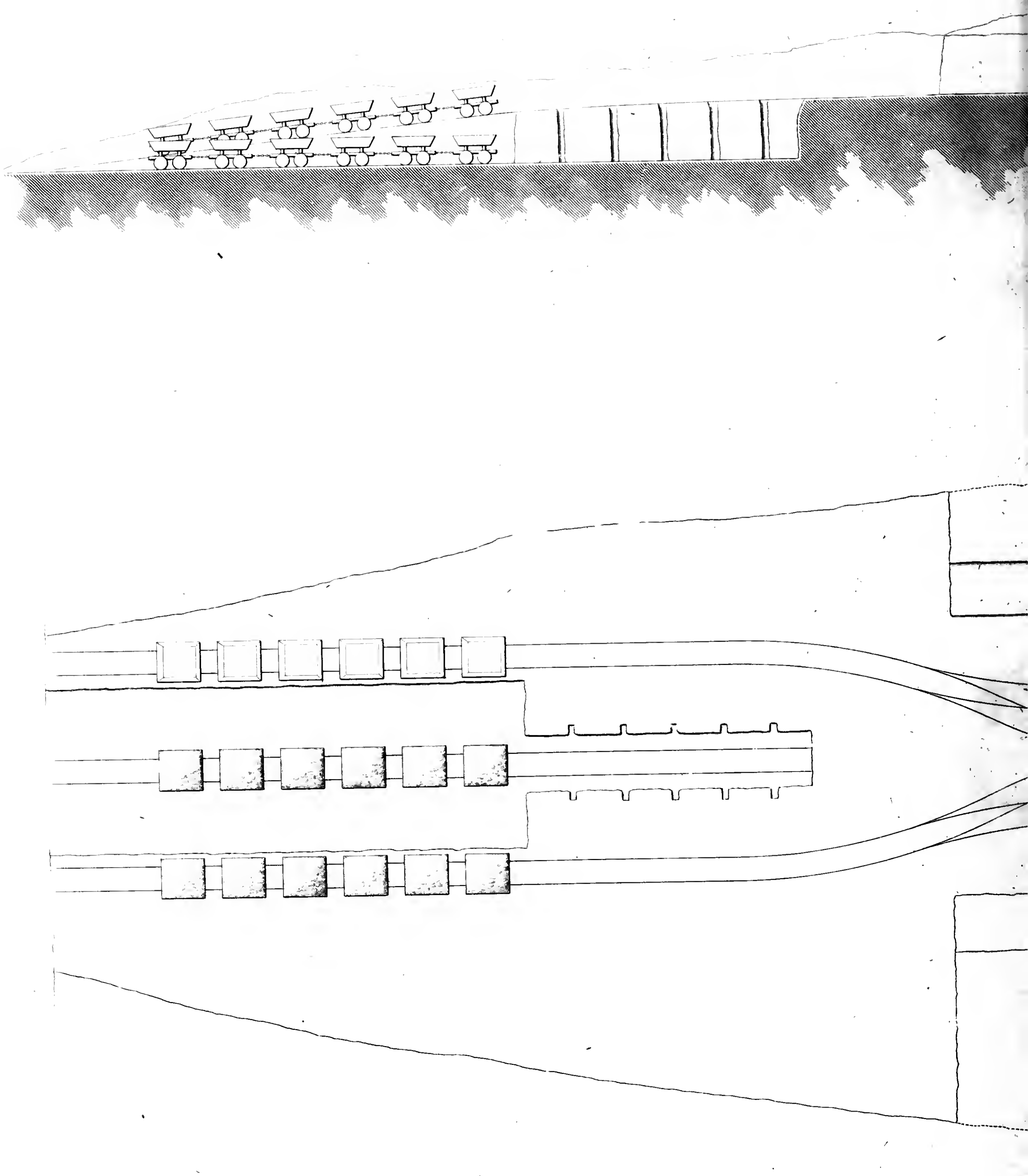

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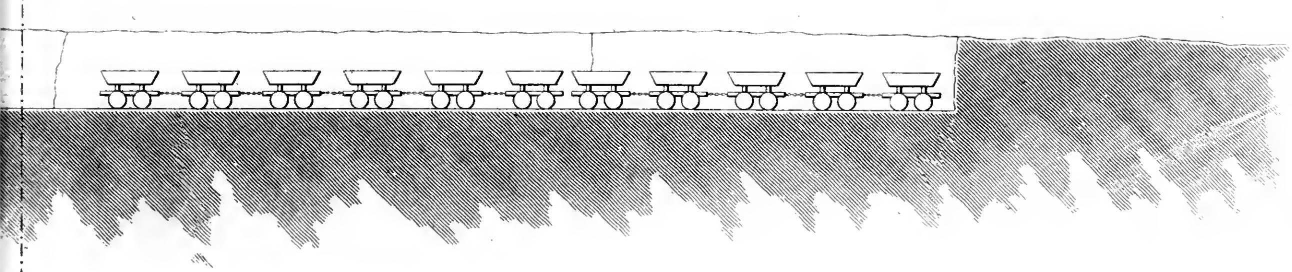
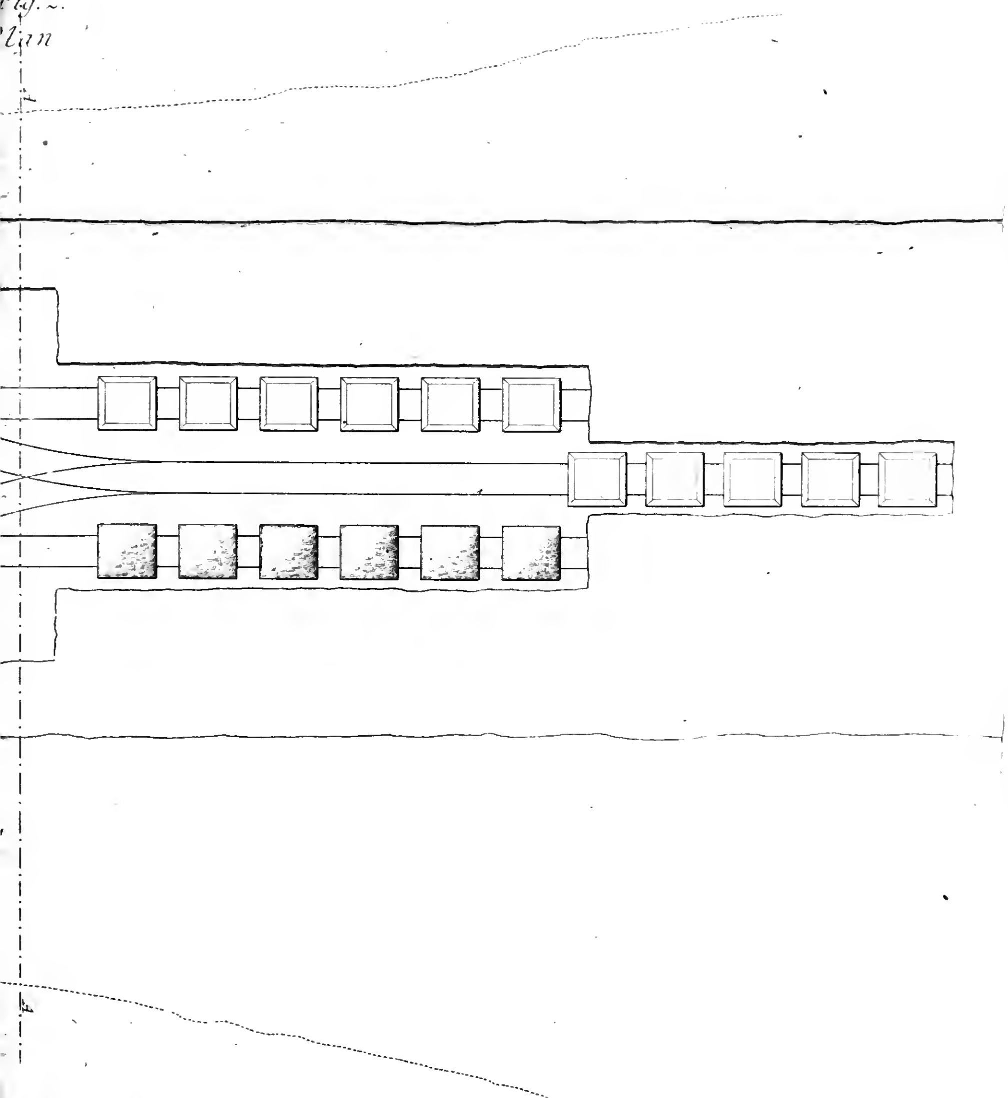
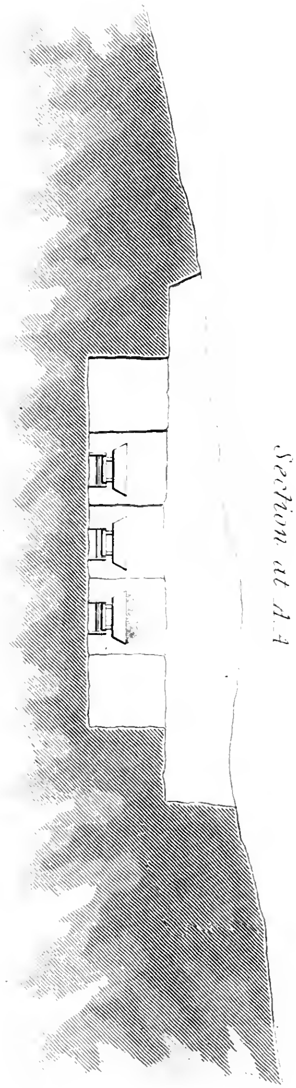


Fig. 2.
Plan





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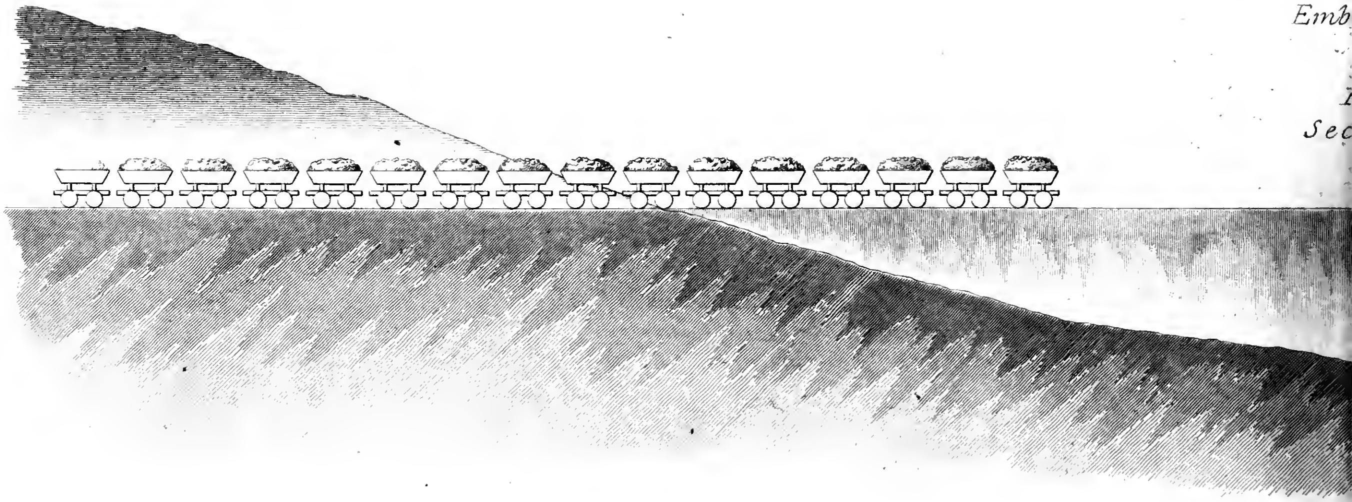

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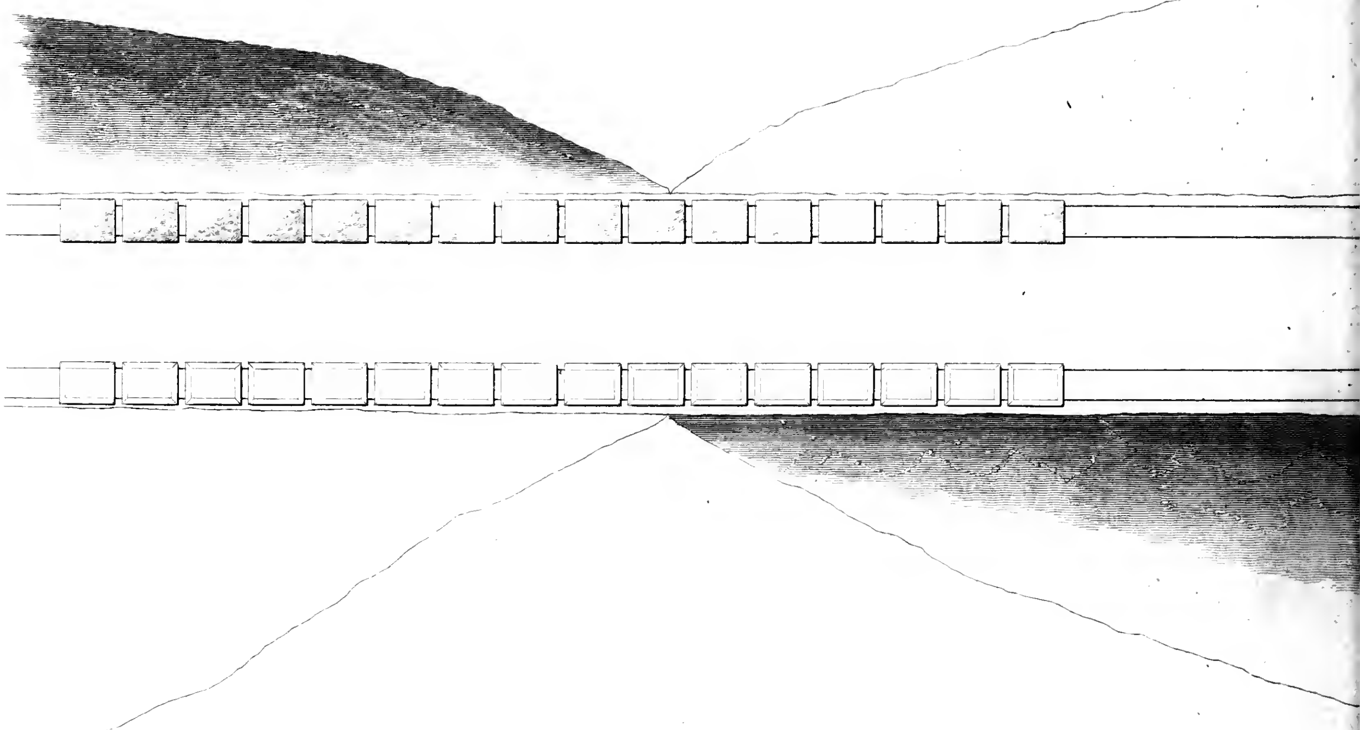

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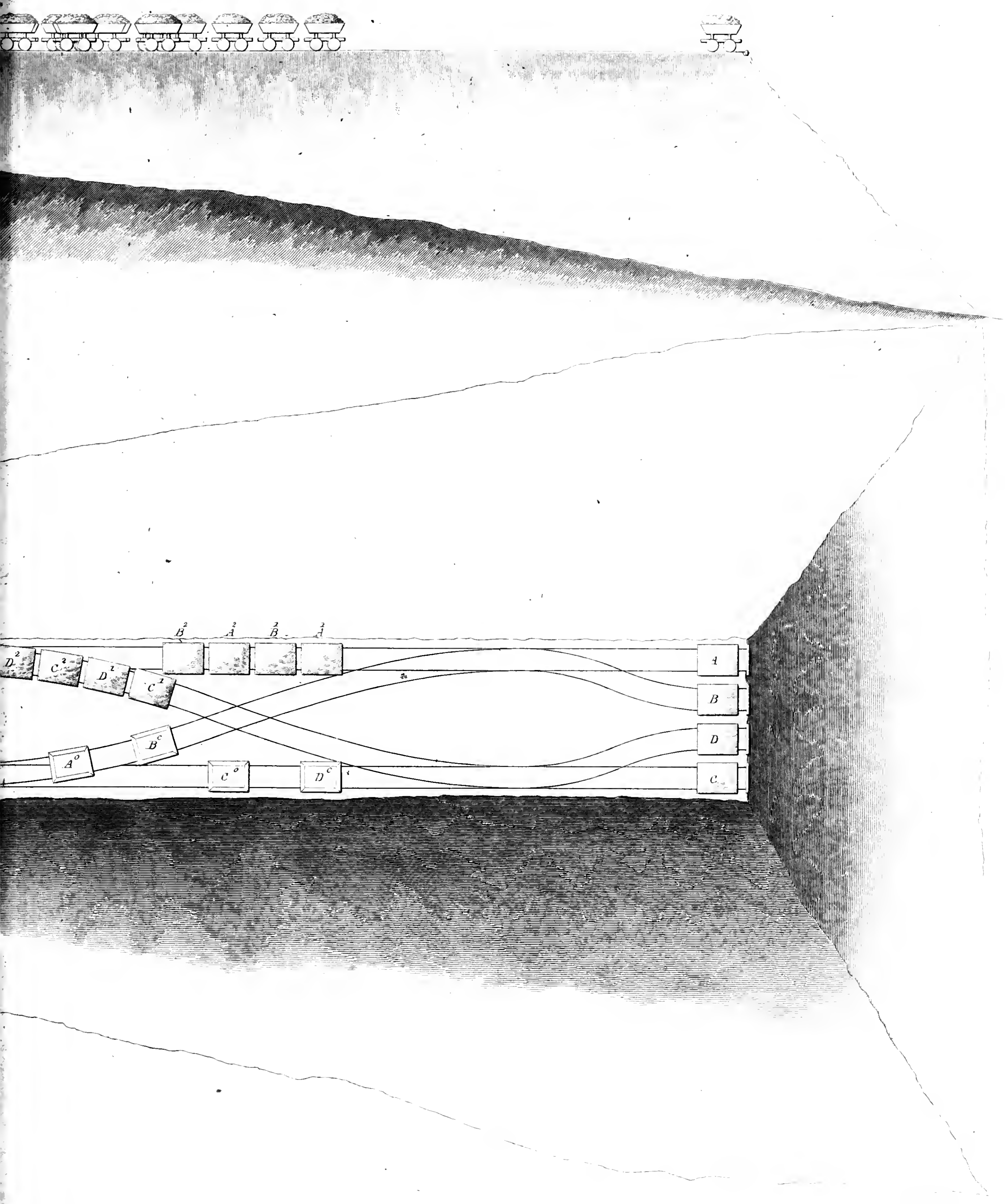

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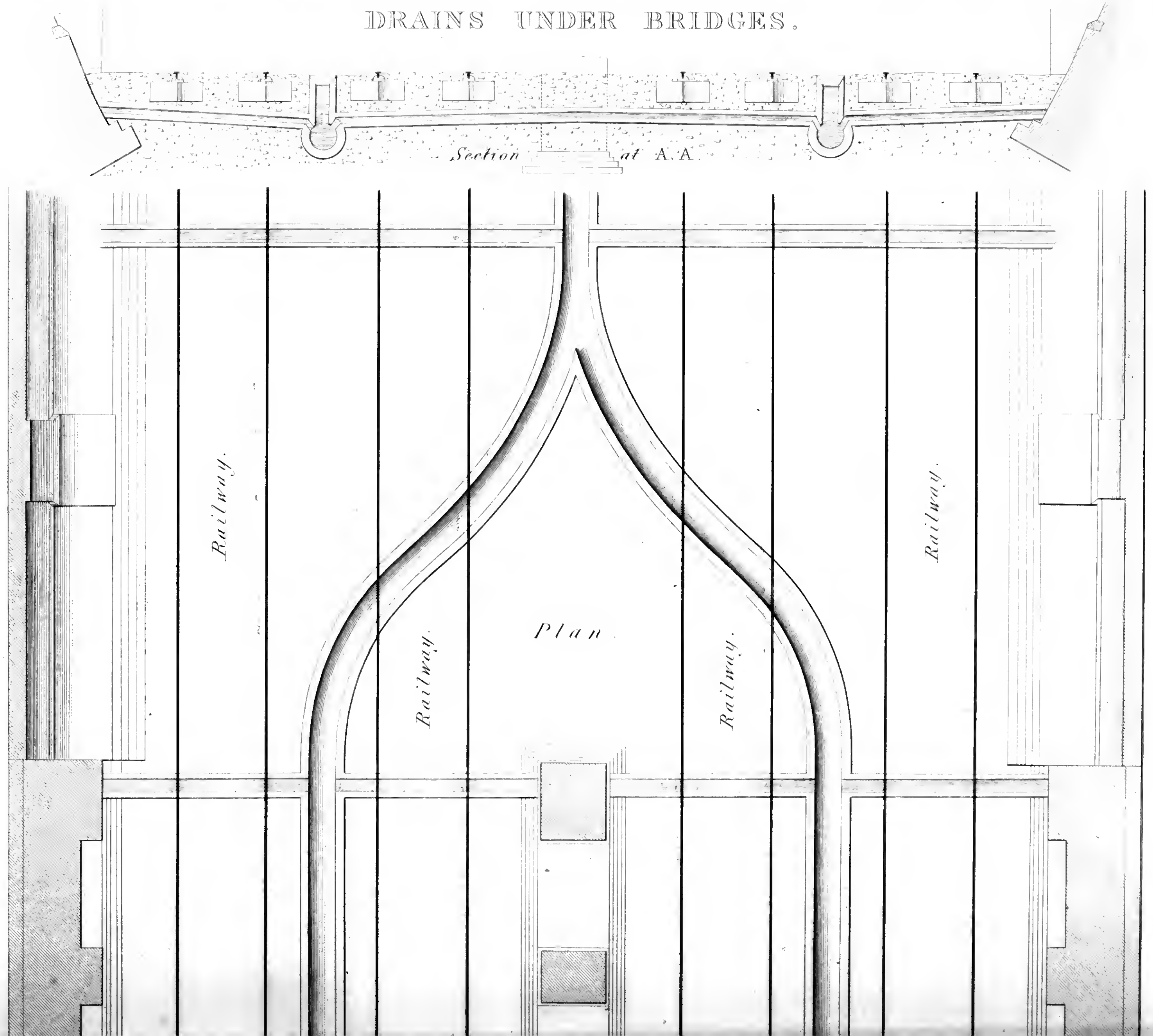
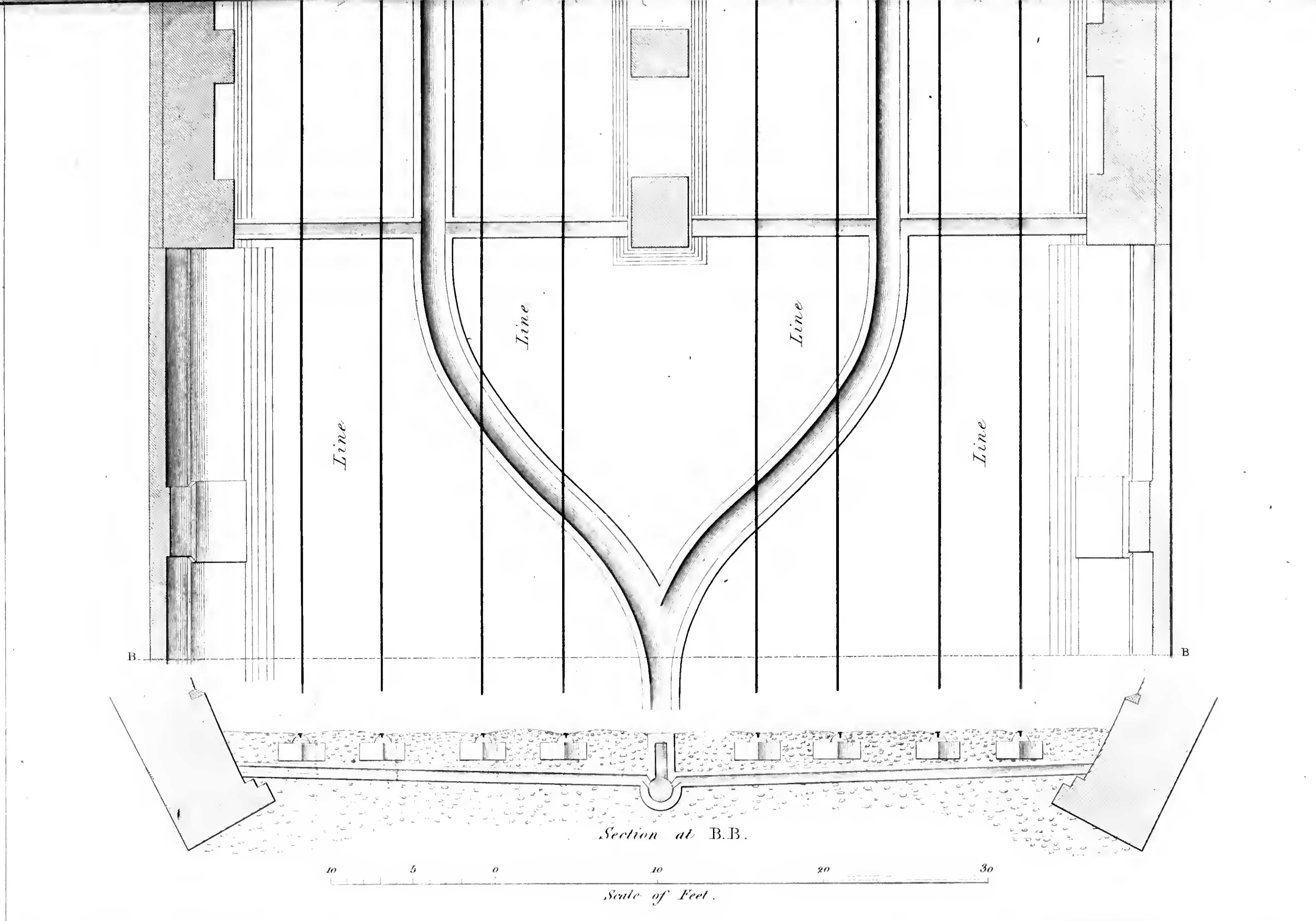
DRAINS UNDER BRIDGES.



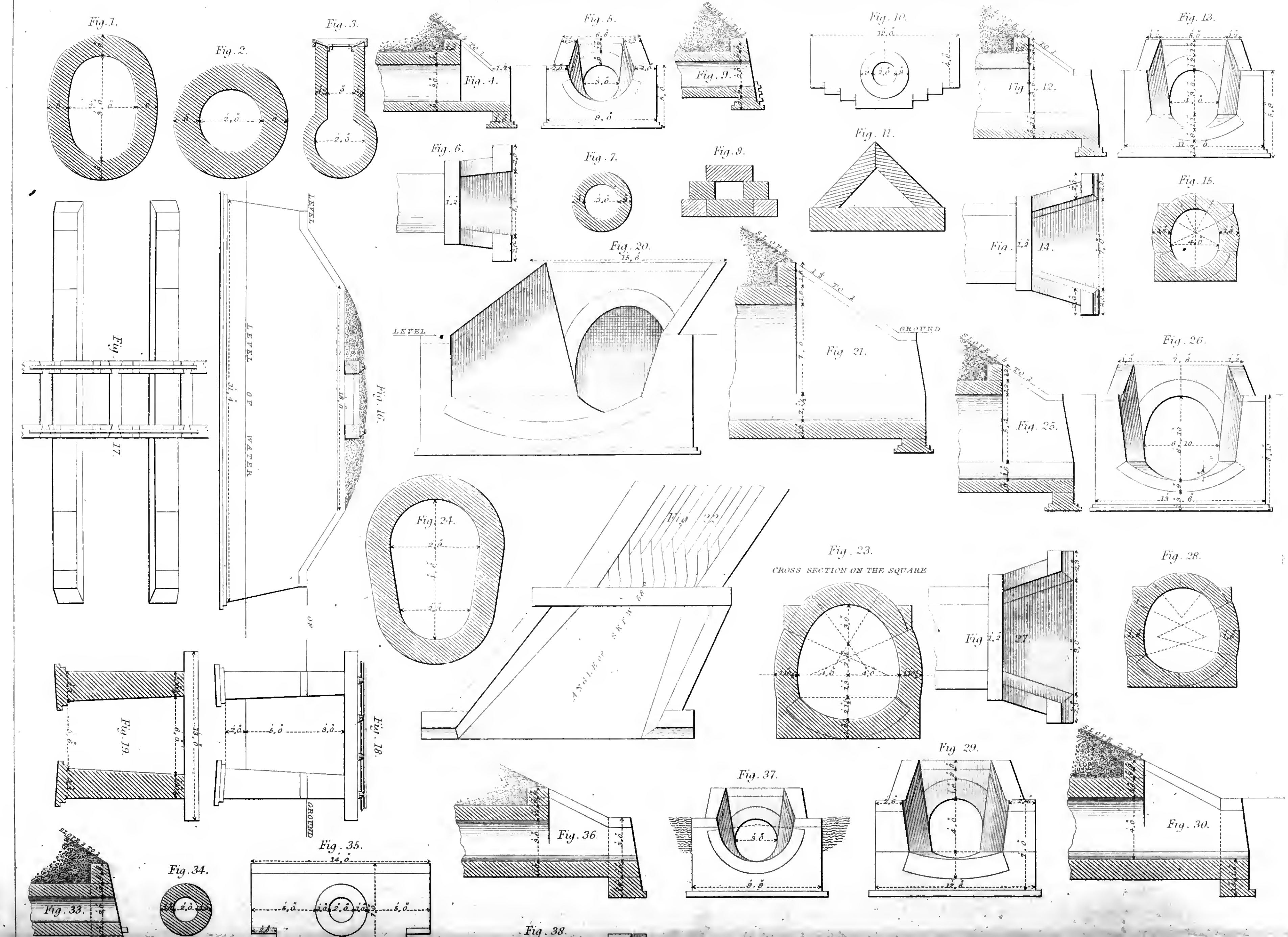


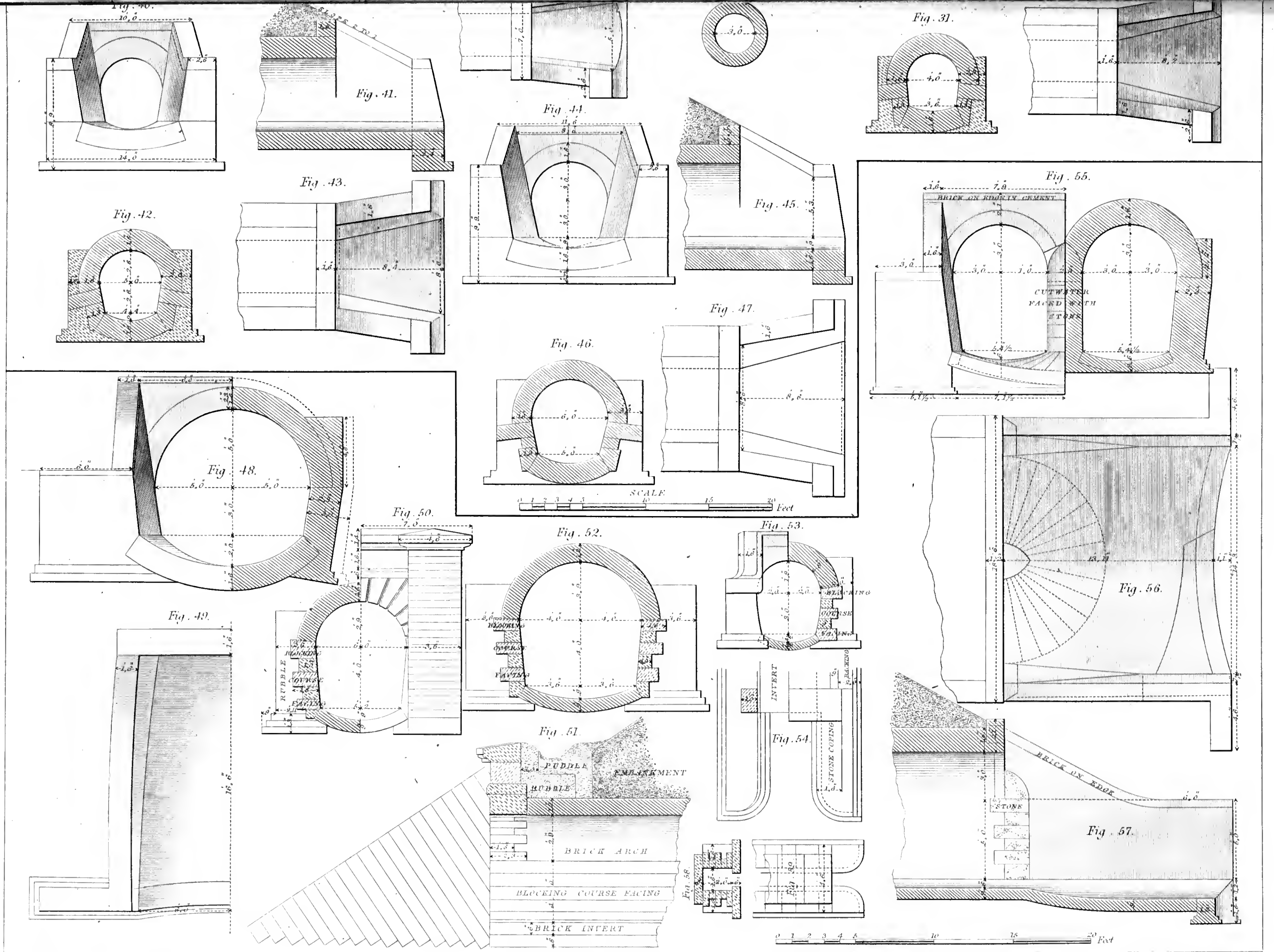
G.D. Dempsey del.

J.H. Le Keux sculp.

London. Published by John Weale, 59, High Holborn, 1844.

BRICK AND STONE CULVERTS





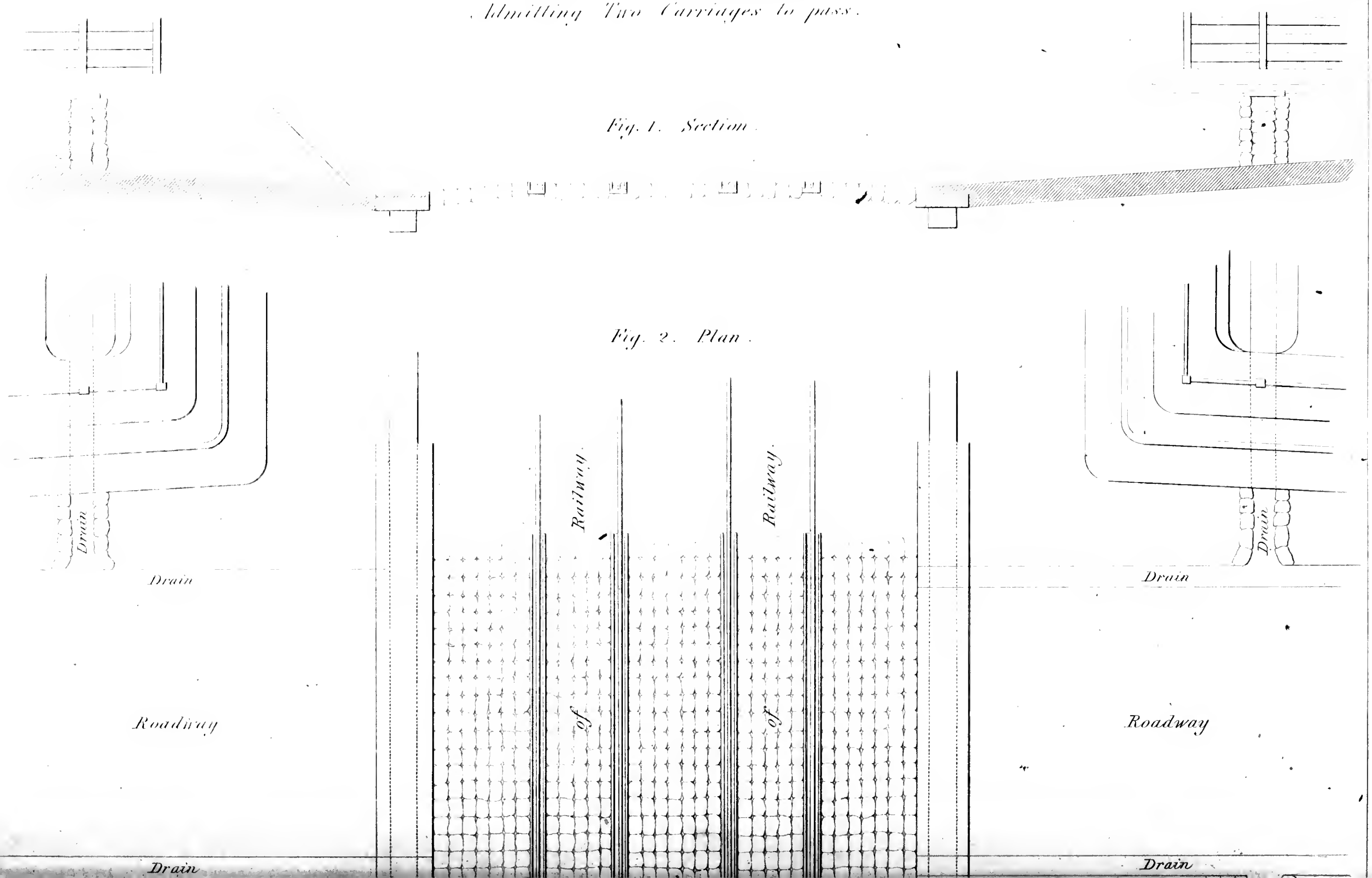
G. D. Dempsey del.

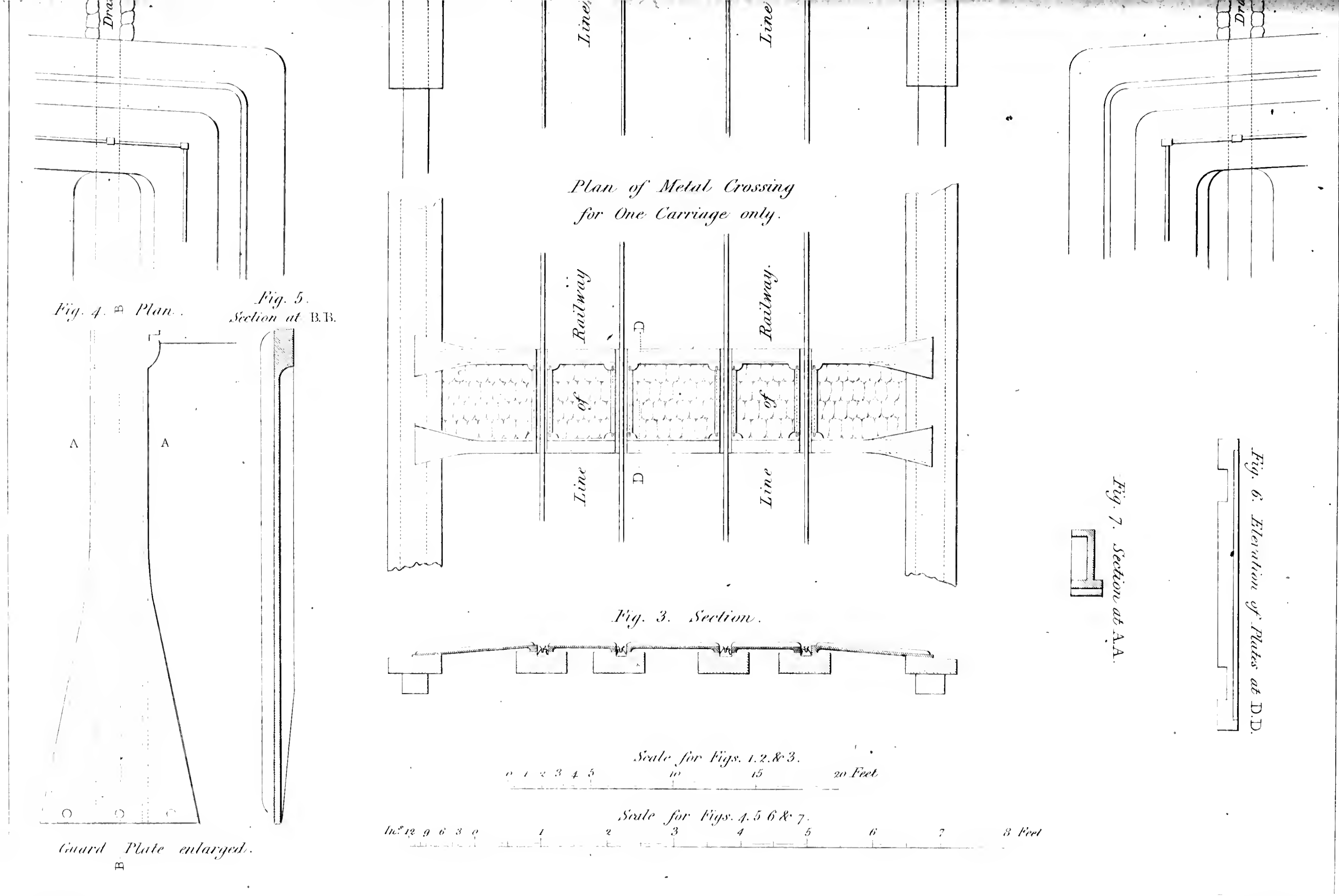
John Weale, Architectural Library, 59 High Holborn.

W. A. Beever Sc.

PAVED CROSSING,

Admitting Two Carriages to pass.





G. D. Dempsey del.

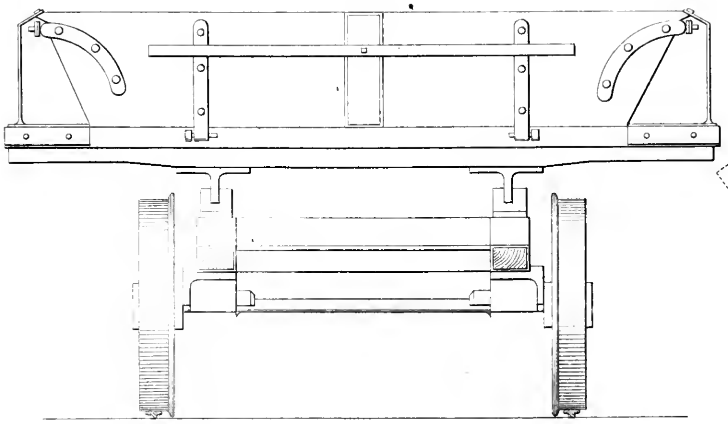
J. H. Le Keux sculp.

London. Published by John Weale, 59, High Holborn, 1844.

EART

WAG

Fig. 1.



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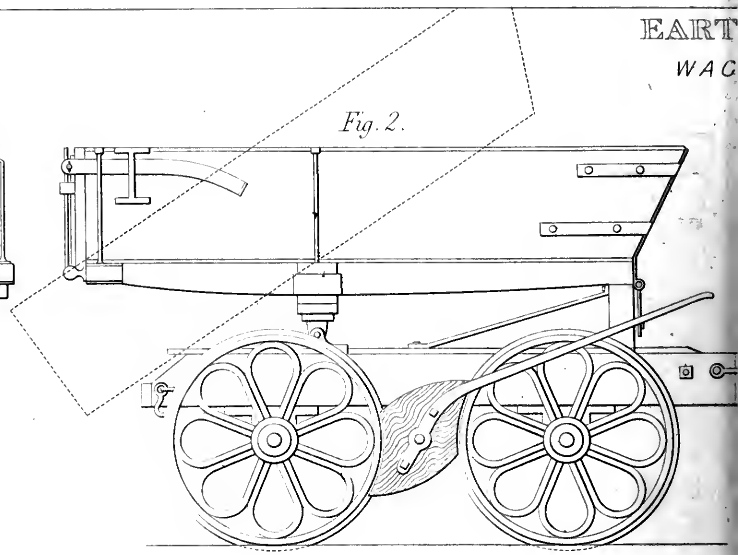

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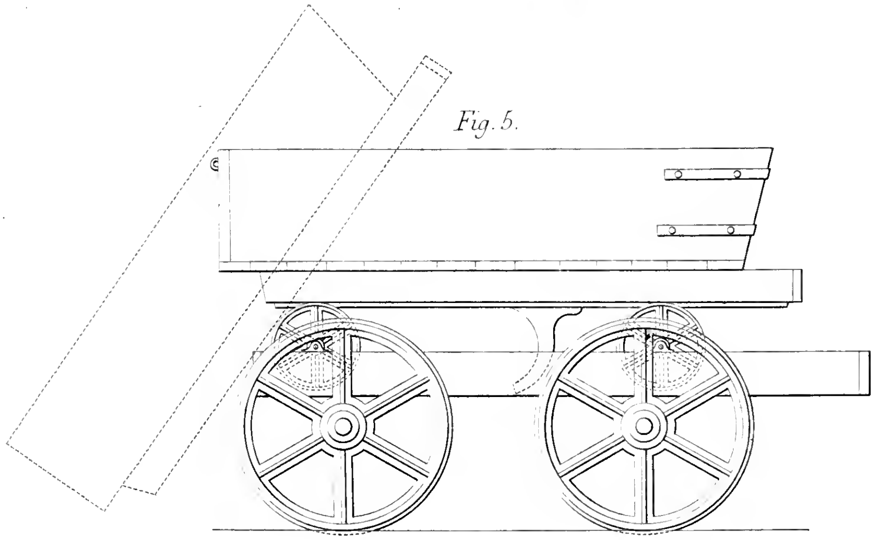

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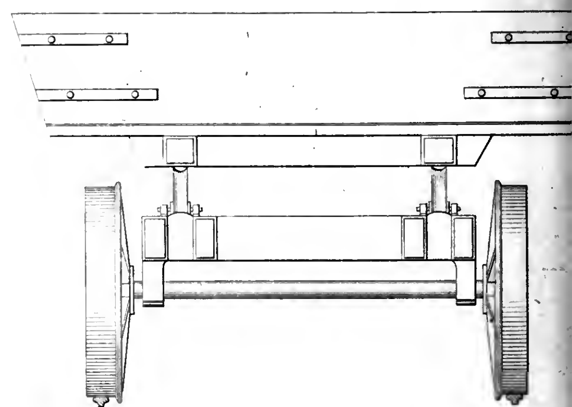

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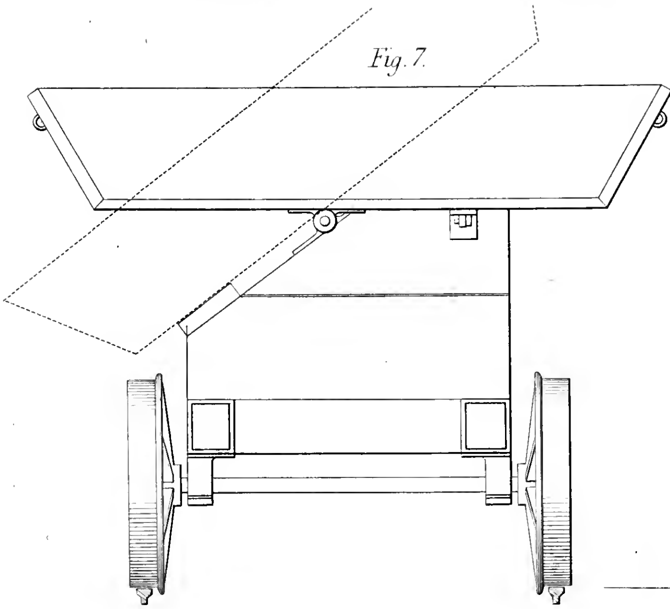

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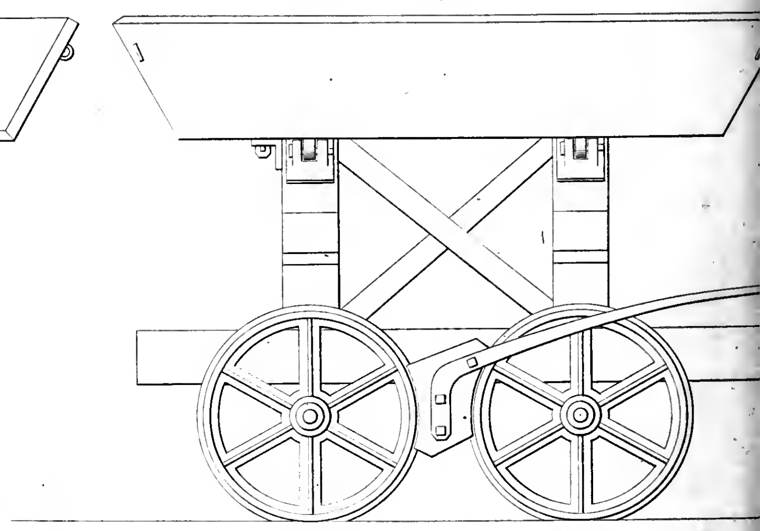


G.D. Dempsey, Del.t

John Weale, Architect

Fig. 3.

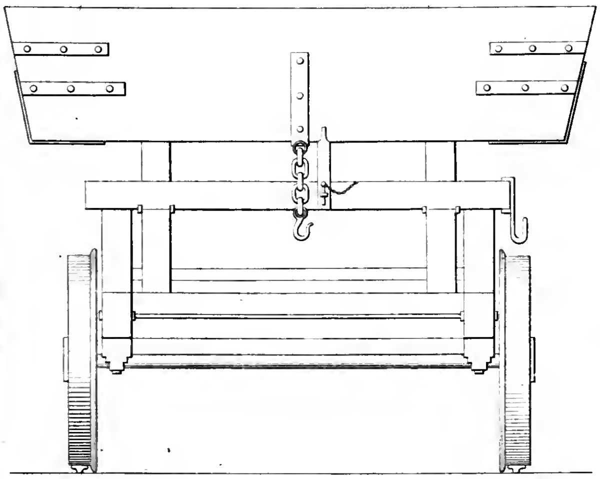


Fig. 4.

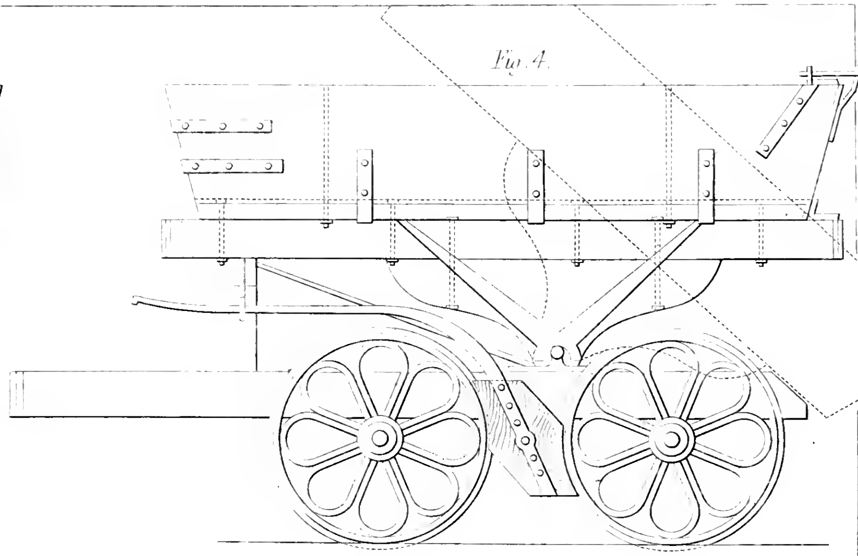
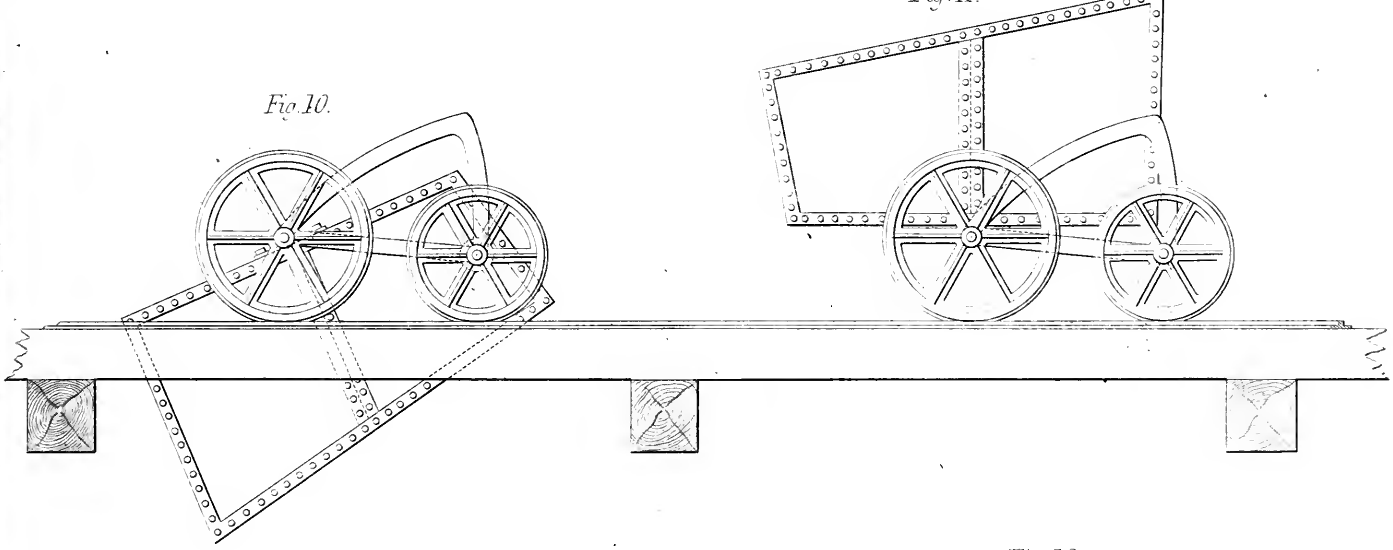


Fig. 11.

Fig. 10.



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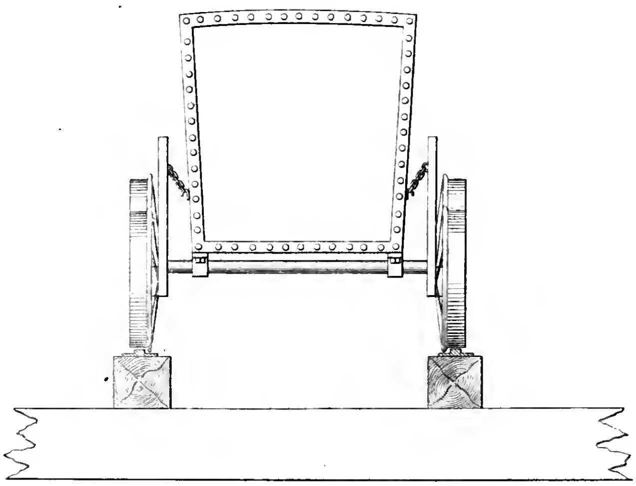

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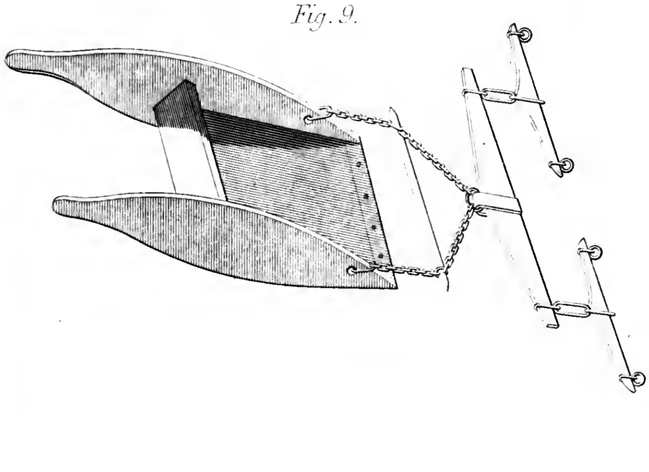
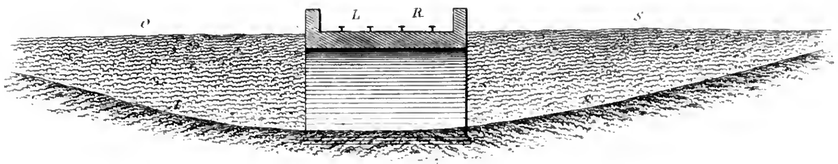


W.A. Beevor S.

RAILWAY BRIDGES.

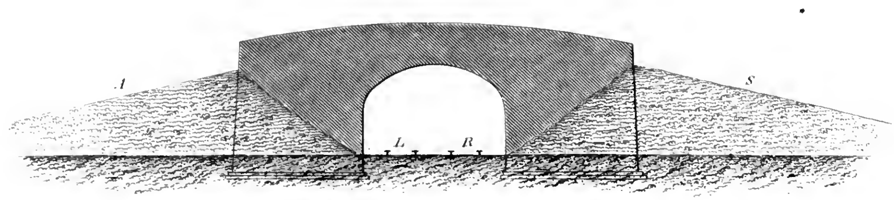
A

Fig. 1.



B

Fig. 1



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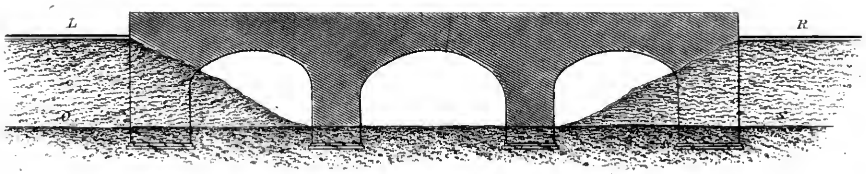
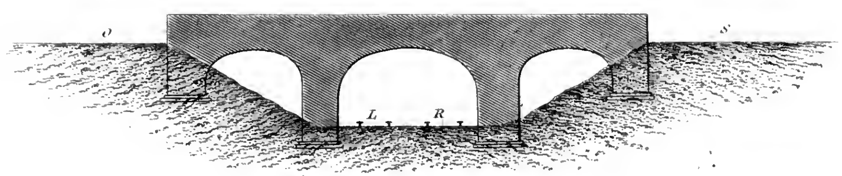


Fig. 2.



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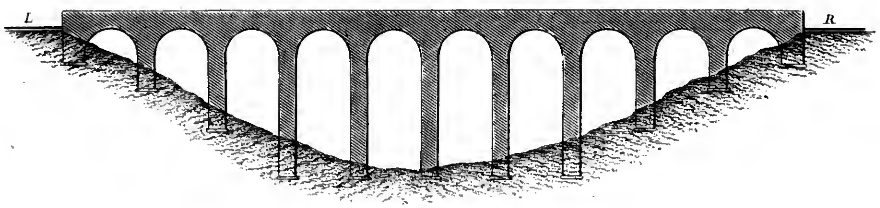
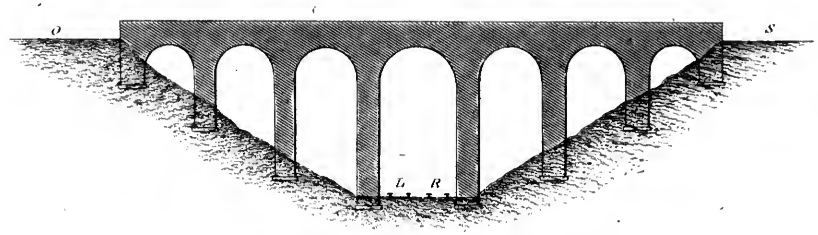


Fig. 3.



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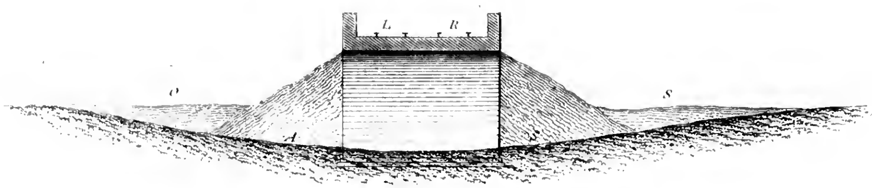

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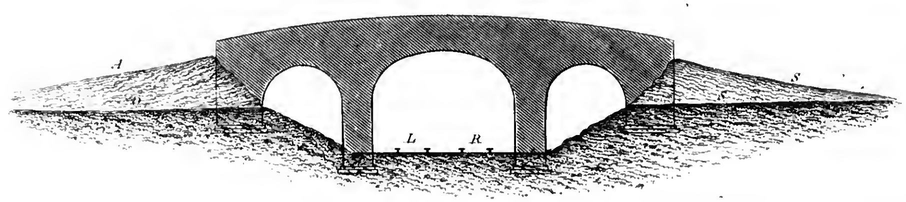


G. D. Dempsey del. B. R. Davies fc.

London Published by John Weale 59 High Holborn [illegible]

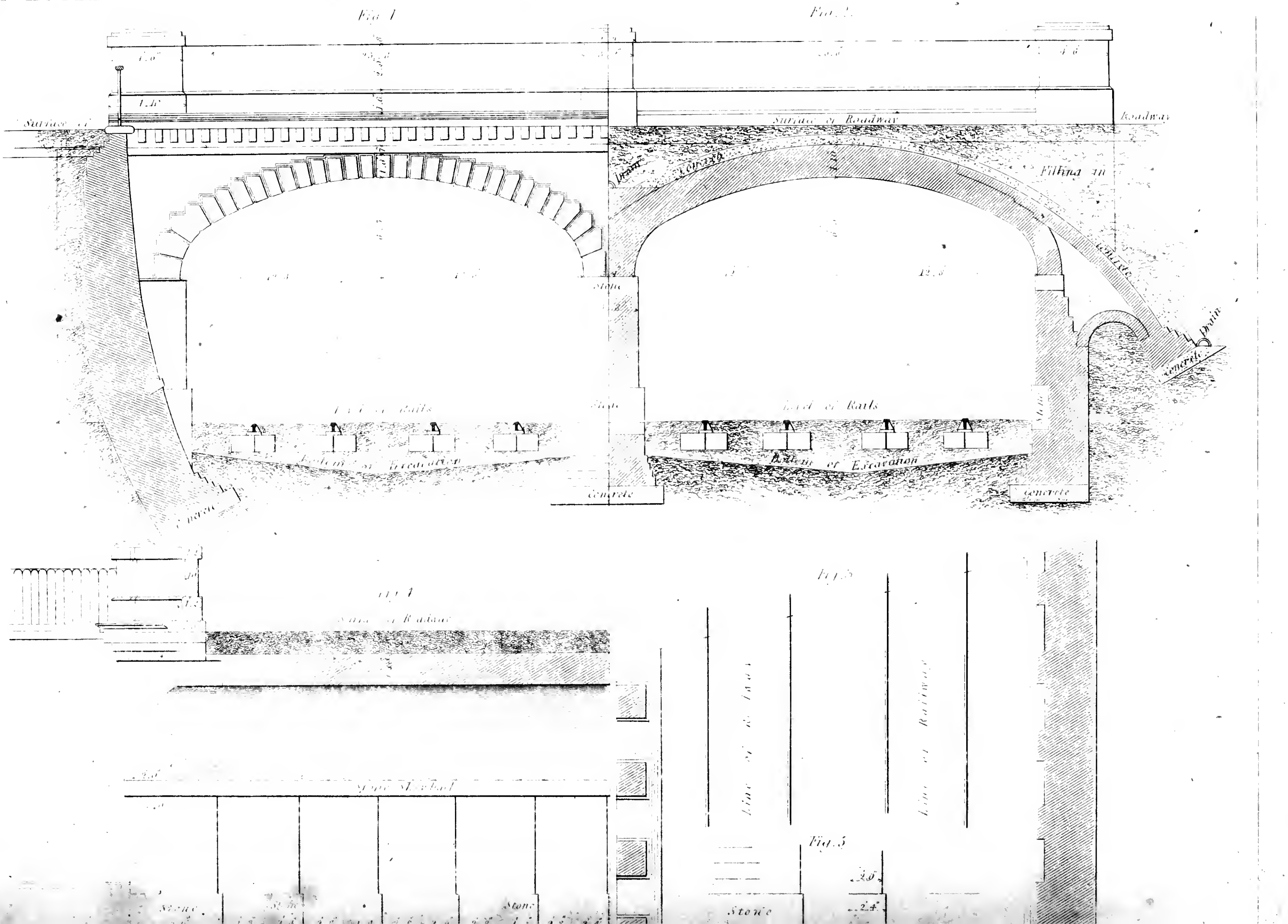
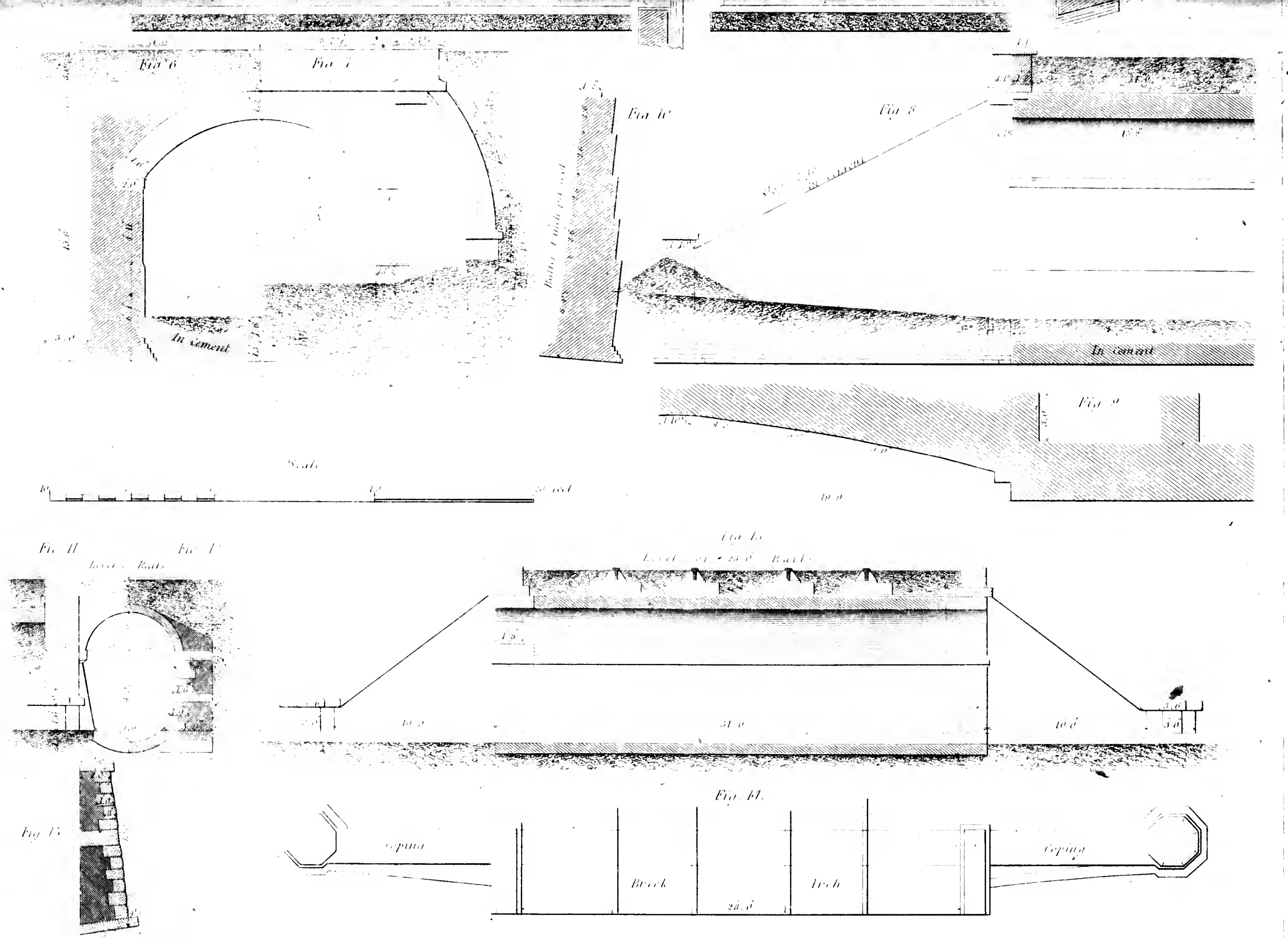


Fig. 1
Fig. 2
Surface of Roadway
Roadway
Filling in
Concrete
Stone
Level of Rails
Bottom of Excavation
Drain
Fig. 4
Fig. 3
Fig. 5
Line of Railway
Stone



G.D.Dempsey del.

B R Davies sc.

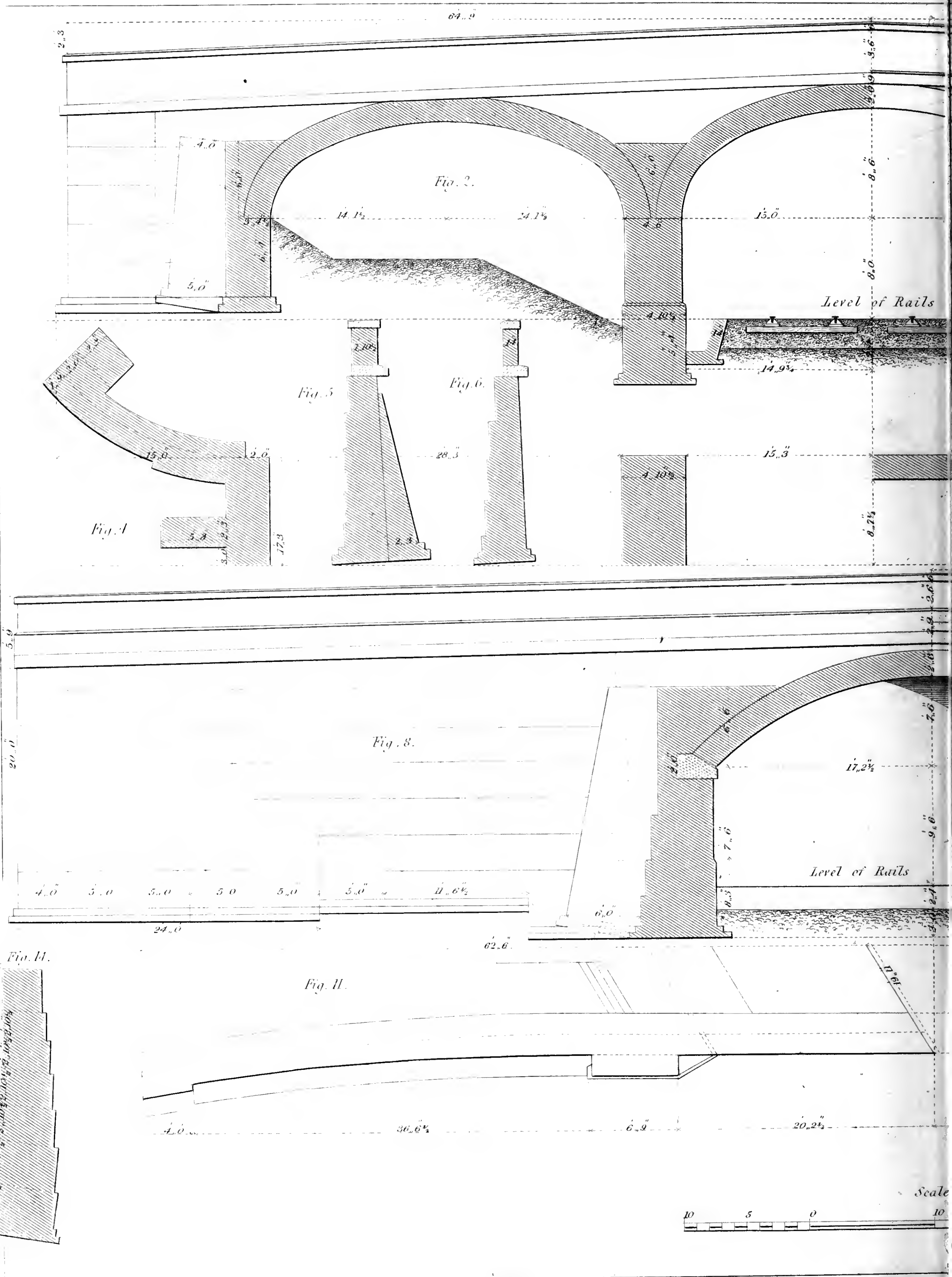


Fig. 2.
Level of Rails
Fig. 4
Fig. 5
Fig. 6.
Fig. 8.
Level of Rails
Fig. 11.
Fig. 14.
Radius 137.3
Scale
10
5
0
10

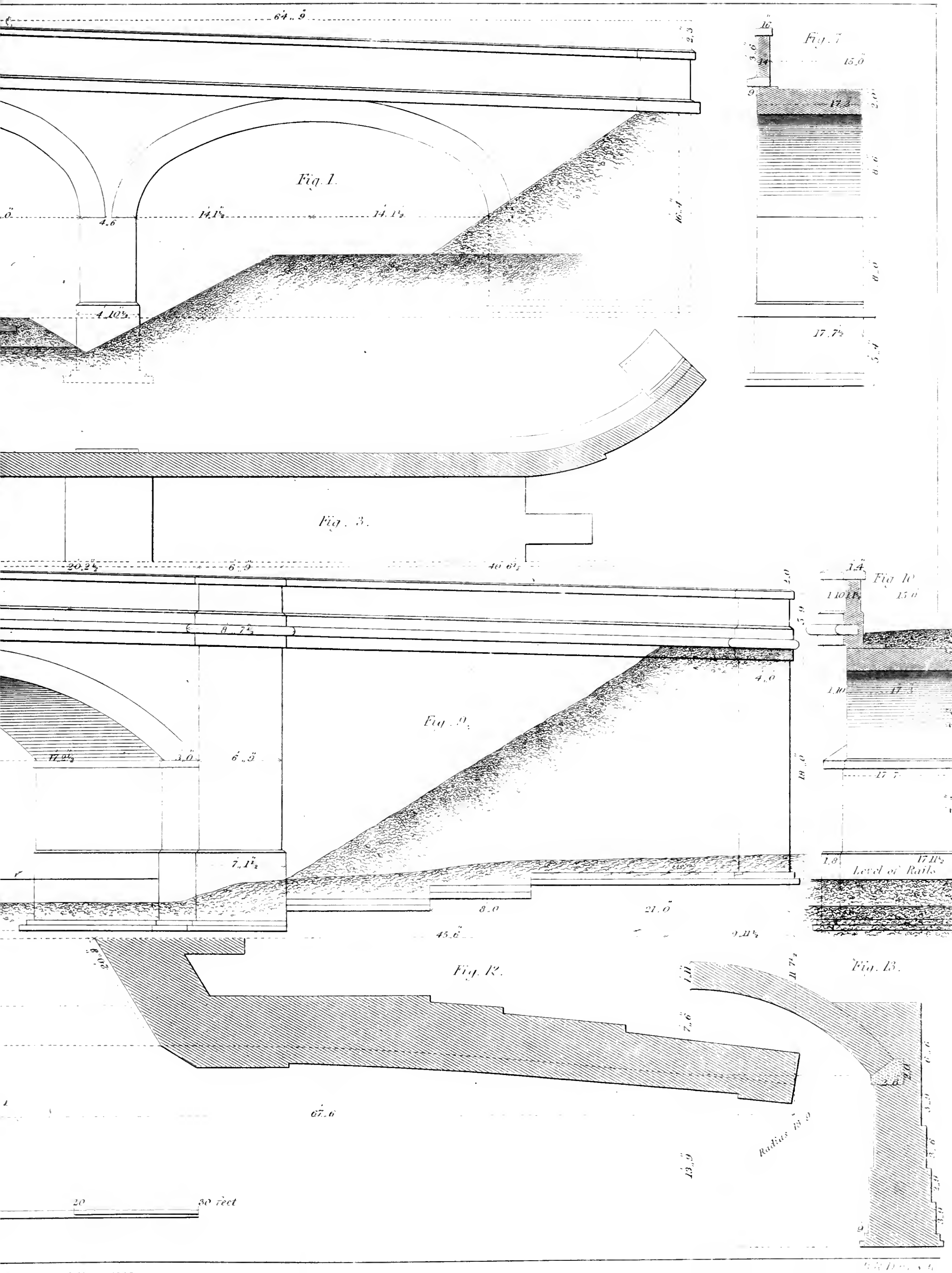


Fig. 1.
Fig. 3.
Fig. 7
Fig. 9.
Fig. 10
Fig. 12.
Fig. 13.
Level of Rails
Radius 13.9
20
30 Feet
64 „ 9
14.1½
4.6
4.10½
17.7½
20.2½
6.5
46.6½
8.7½
17.9½
3.0
7.1½
45.6
21.0
8.0
67.6

Fig. 1

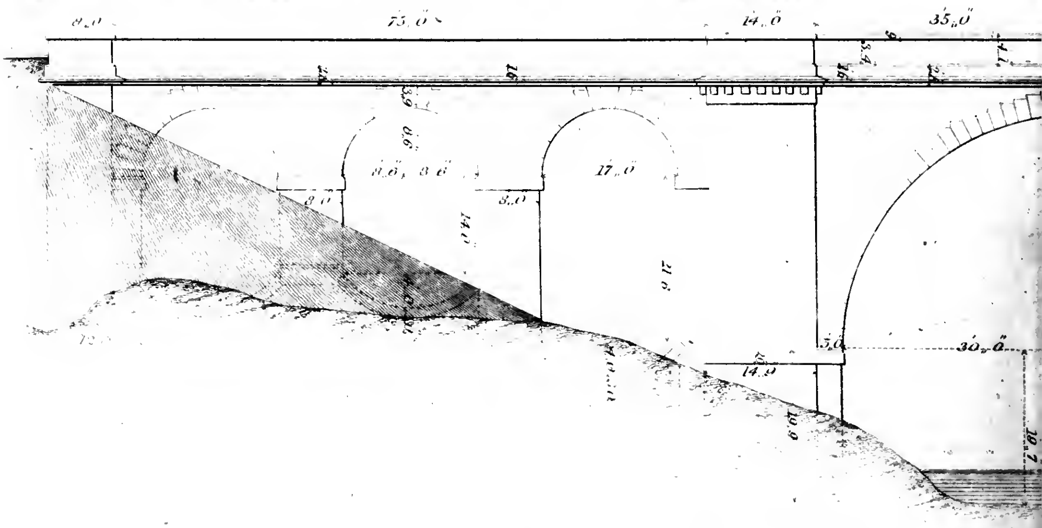


Fig. 3

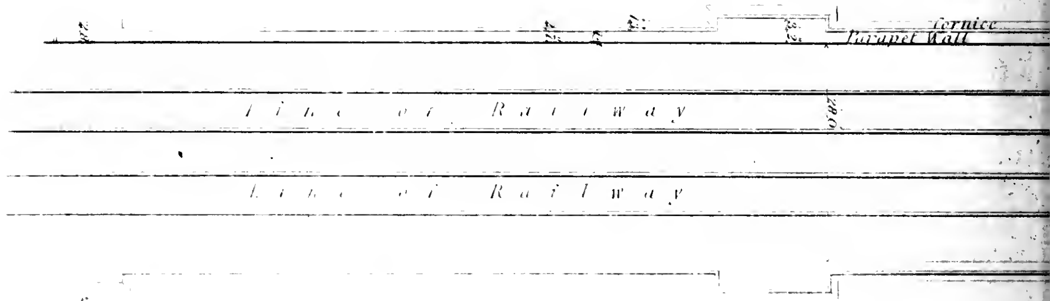


Fig. 5

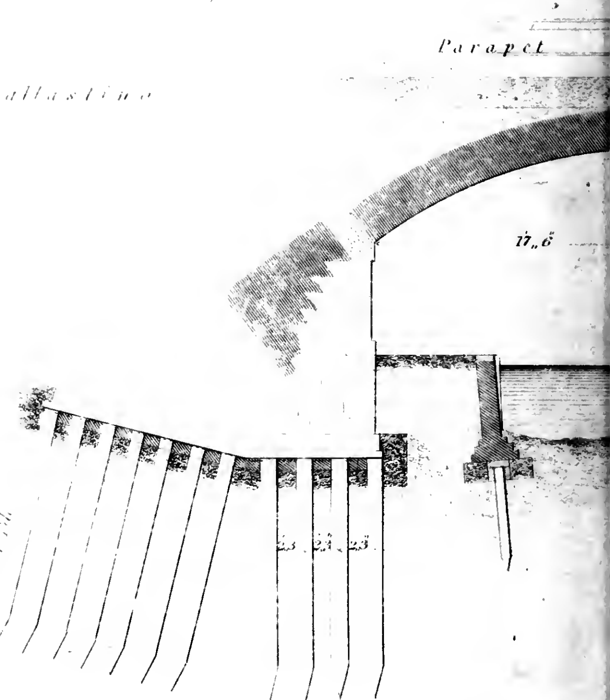
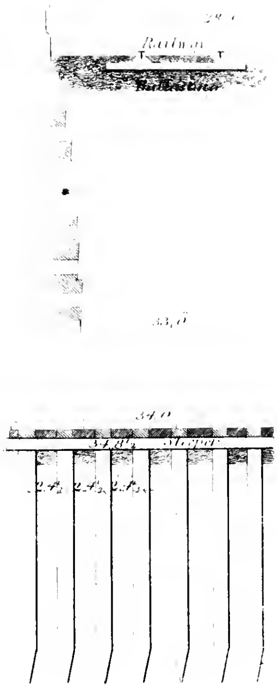
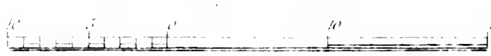


Fig. 7



Scale for Figs. 5 6 7 8 9 & 10.



Scale for Figs. 1 2 3 & 4

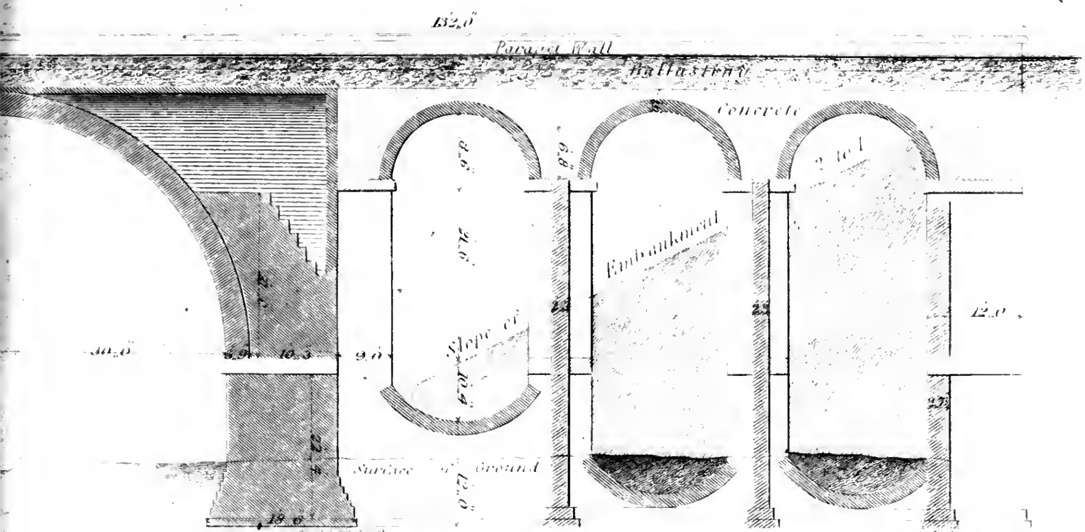


Fig. 2.

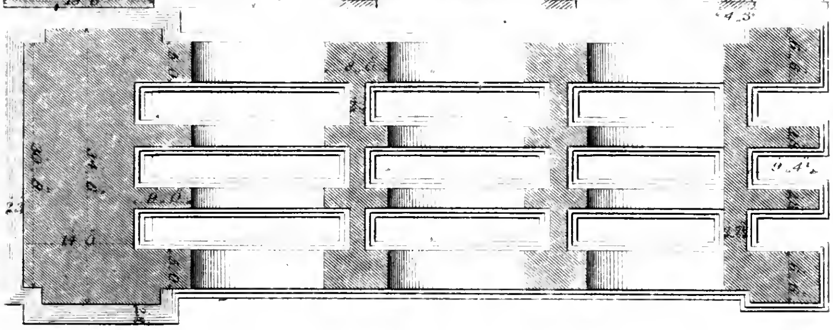


Fig. 1.

Fig. 6

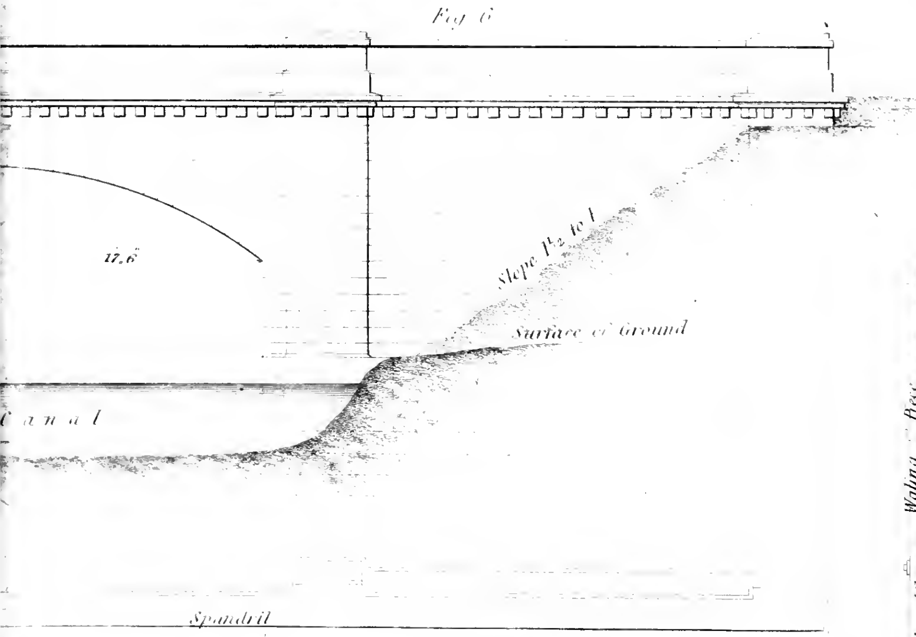


Fig. 10

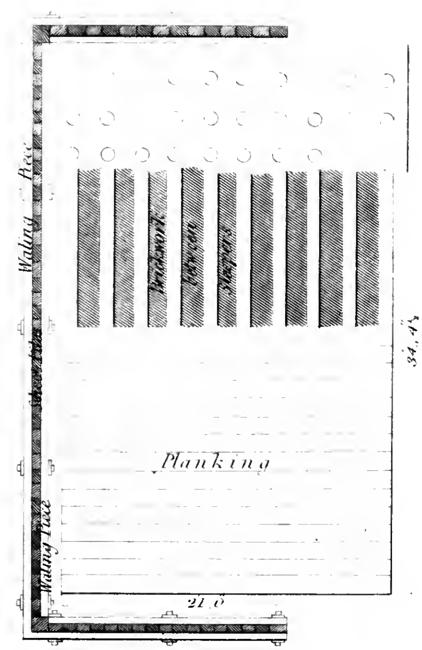


Fig. 8.

Abutment

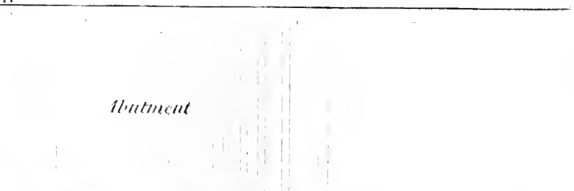
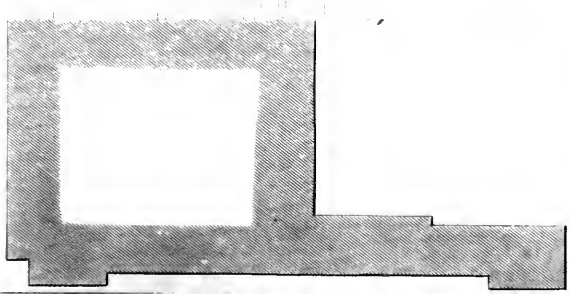
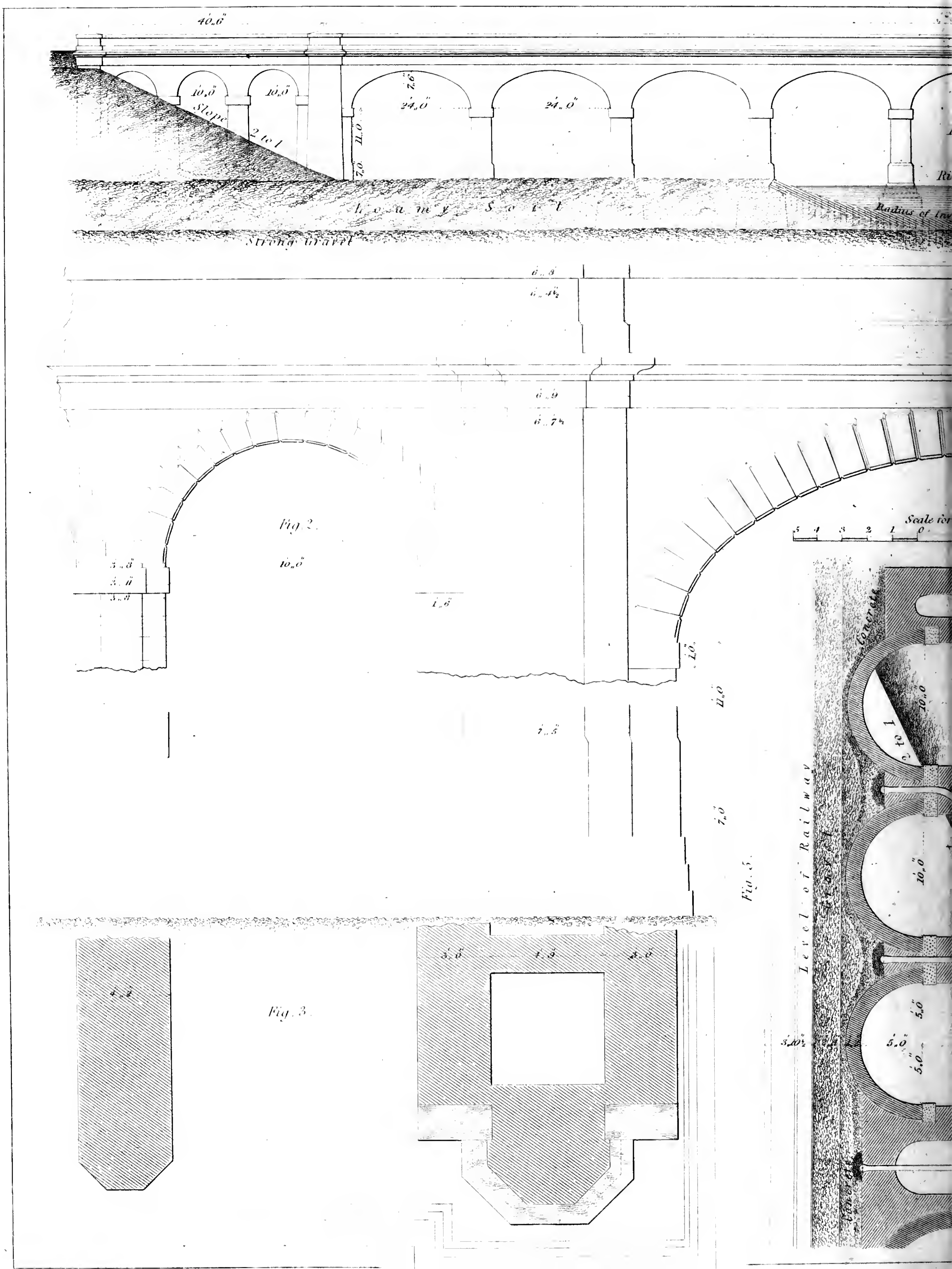
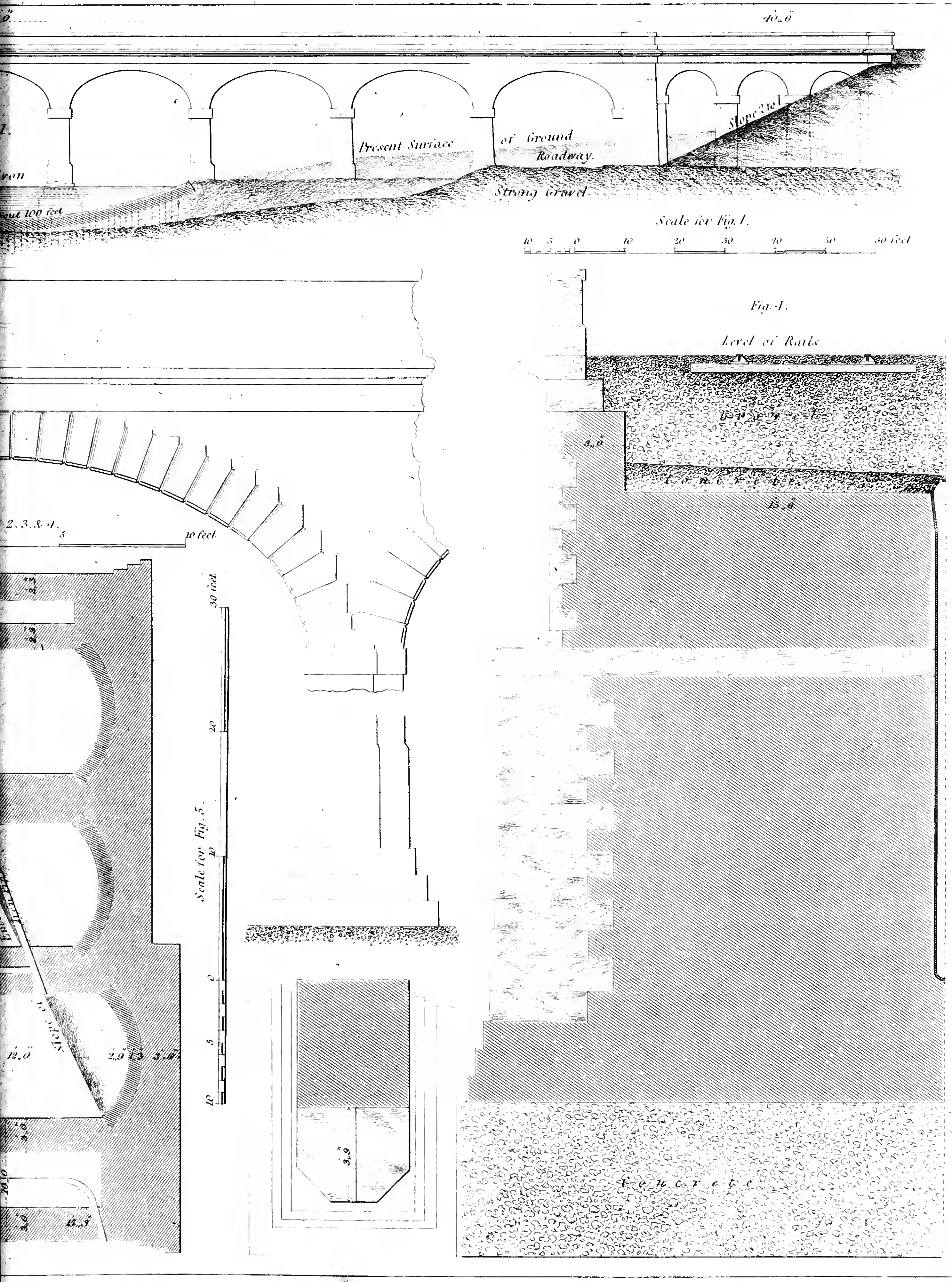


Fig. 9.





40,,0"
10,,0"
10,,0"
Slope
2 to 1
7,,6"
24,,0"
24,,0"
11,,0
7,,0
Loamy Soil
Strong Gravel
Radius of Inv
6,,3
6,,4½
6,,9
6,,7½
Fig. 2.
10,,0"
3,,8"
3,,11
3,,8
1,,6
1,,0
11,,0
7,,3
7,,0
Scale for
5 4 3 2 1 0
Concrete
10,,0
2 to 1
Level of Railway
Gravel
Fig. 5.
10,,0"
5,,0"
5,,0"
5,,0"
3,,10½
Fig. 3.
3,,6
4,,3
3,,6
4,,2
Concrete


40„6"
Present Surface of Ground
Roadway.
Strong Gravel
Slope 2 to 1
Scale for Fig. 1.
10 5 0 10 20 30 40 50 60 feet
Fig. 4.
Level of Rails
15„6"
3„0"
2. 3. & 4.
5
10 feet
Scale for Fig. 5.
30 feet
20
10
0
5
10
12„0"
2„9"
3„0"
15„3"
3„9"

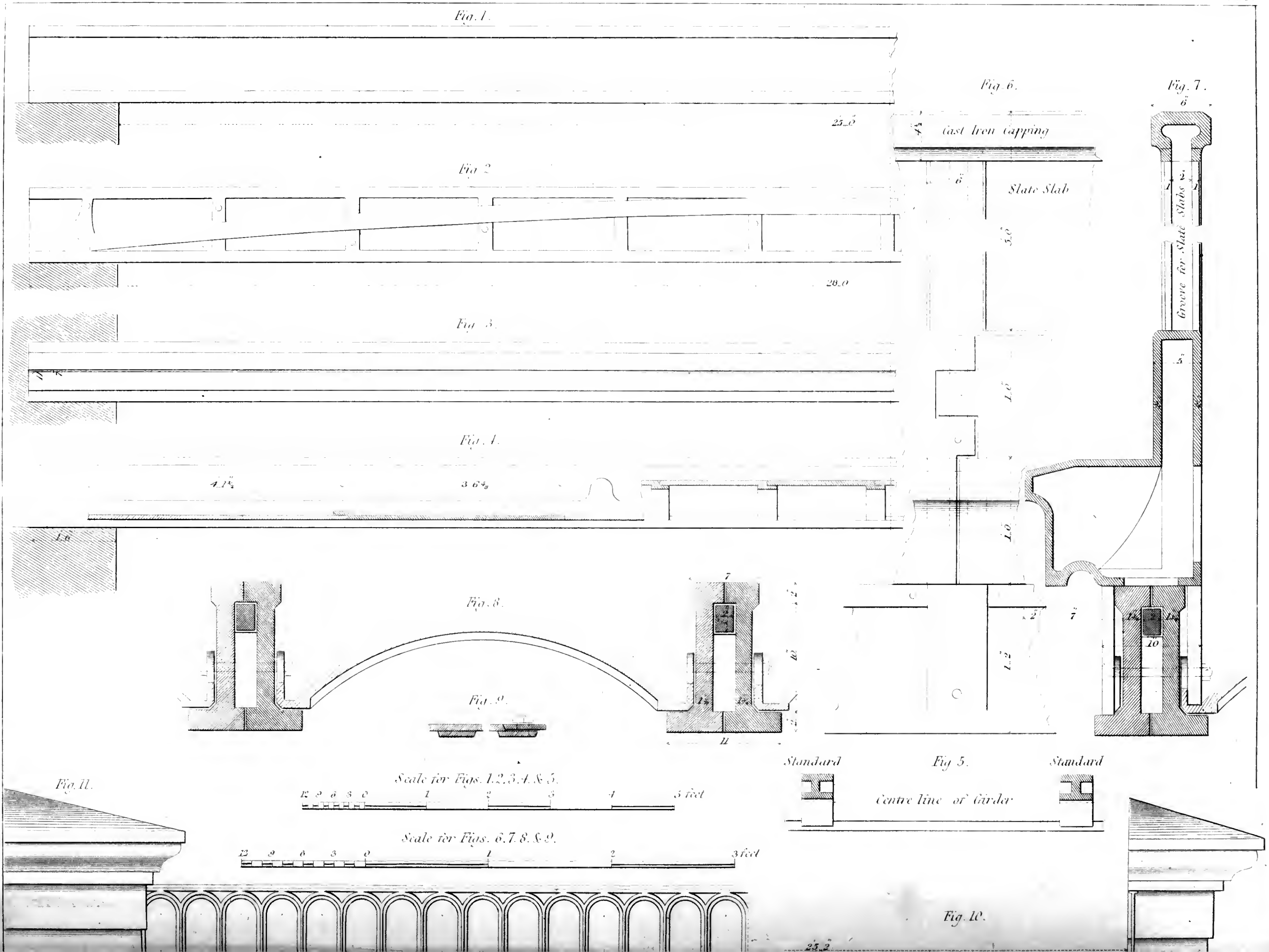
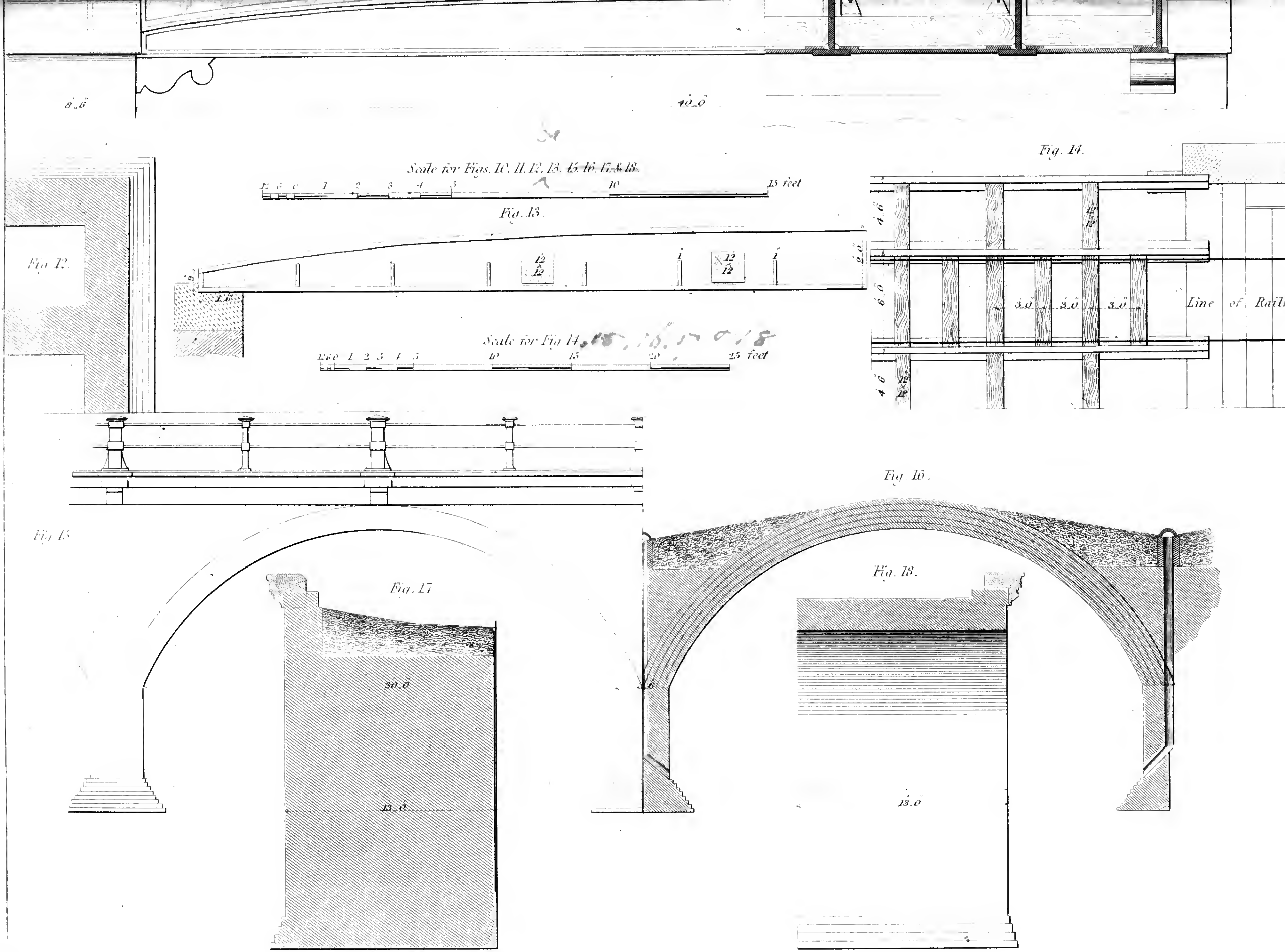


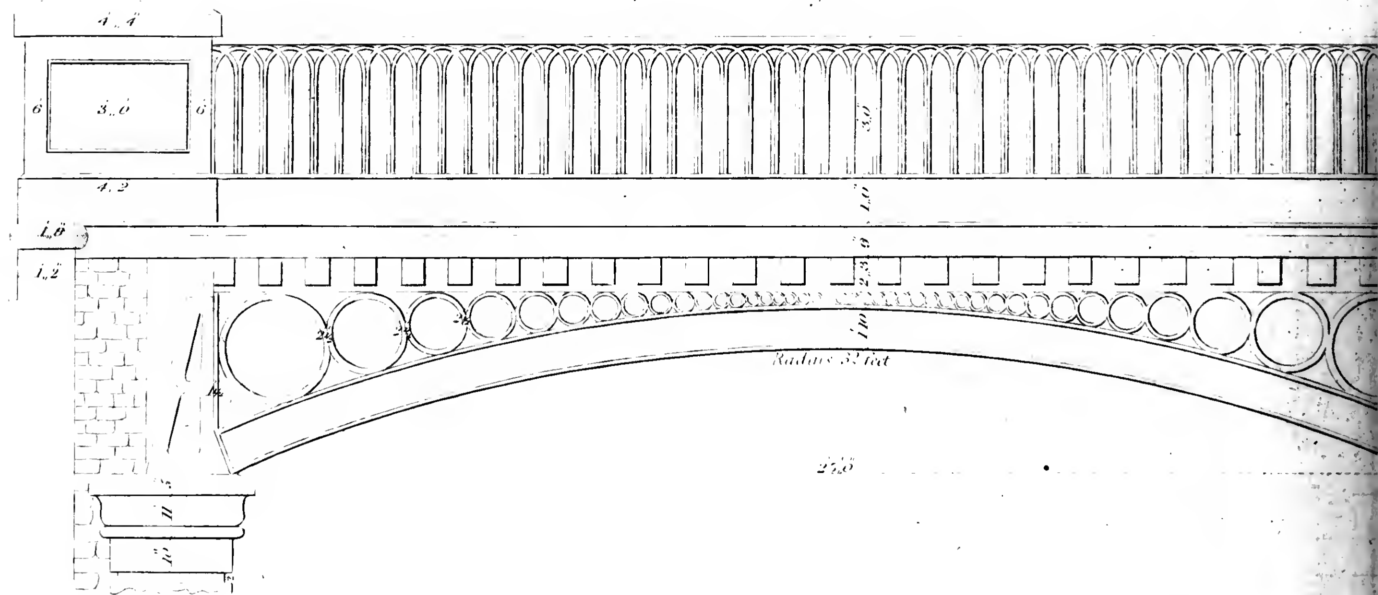
Fig. 1.
25_5
Fig. 2
28_0
Fig. 3.
Fig. 4.
4.1½
3.6⅞
1.6
Fig. 6.
Cast Iron Capping
Slate Slab
Fig. 7.
Groove for Slate Slabs
Fig. 8.
Fig. 9.
Fig. 5.
Standard
Standard
Centre line of Girder
Scale for Figs. 1.2.3.4.&5.
12 9 6 3 0 1 2 3 4 5 feet
Scale for Figs. 6.7.8.&9.
12 9 6 3 0 1 2 3 feet
Fig. 11.
Fig. 10.



B. R. Davies fc.

London Published by John Weale 59 High Holborn 1845

Fig. 1.



Scale for Figs. 1.2.3.4.5.6.7.8.&.9.

0 1 2 3 4 5 10 15 feet

Fig. 2.

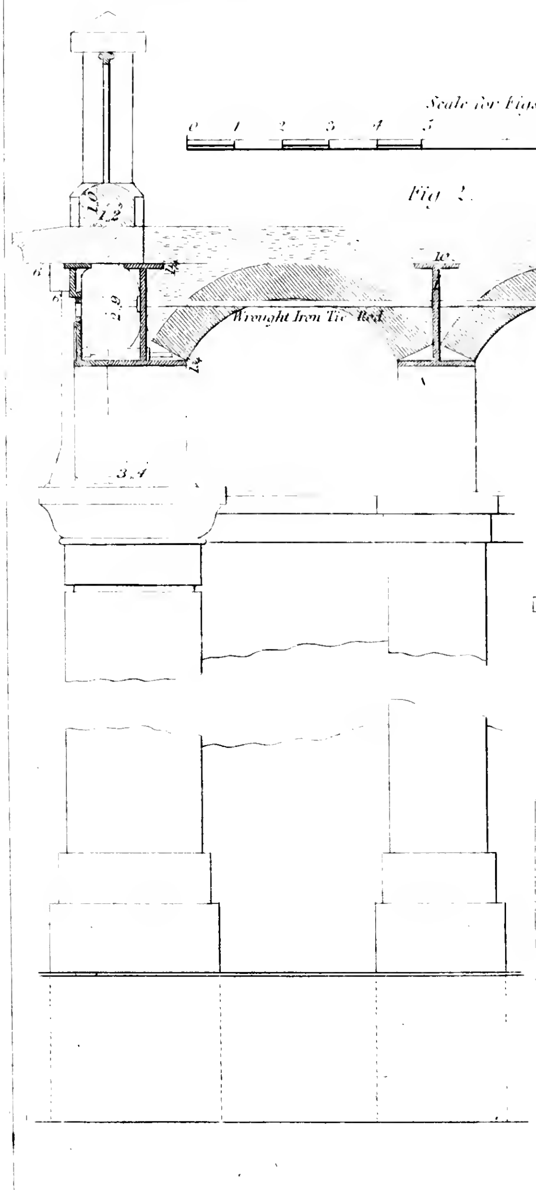
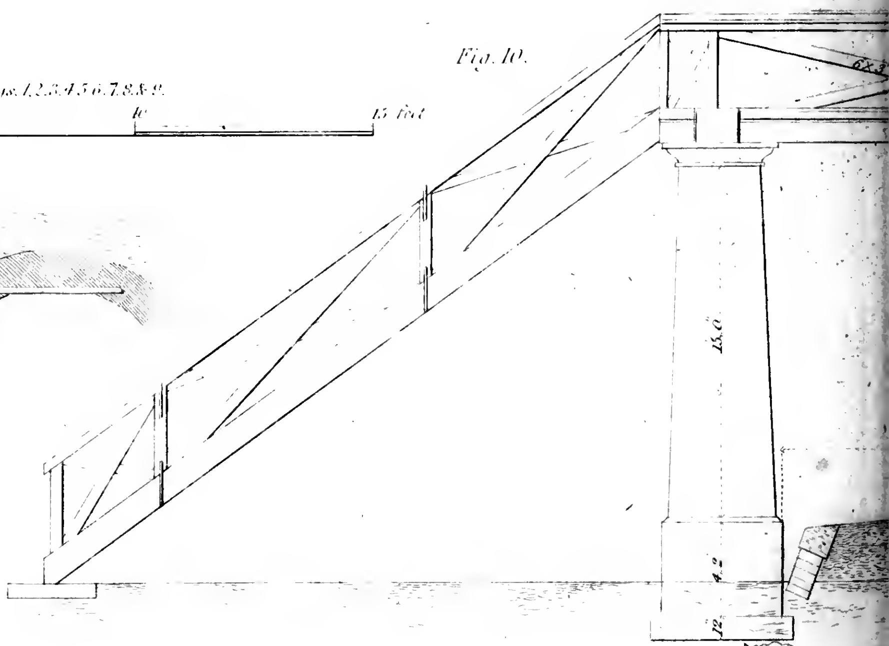


Fig. 10.



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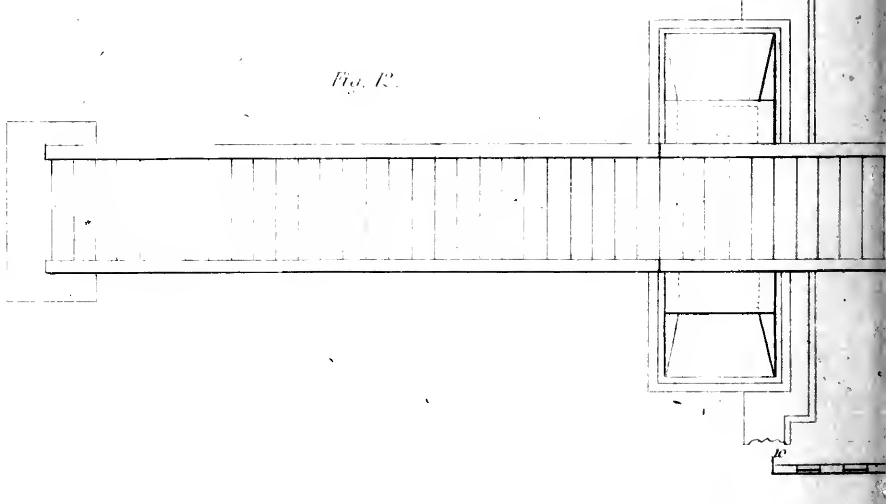
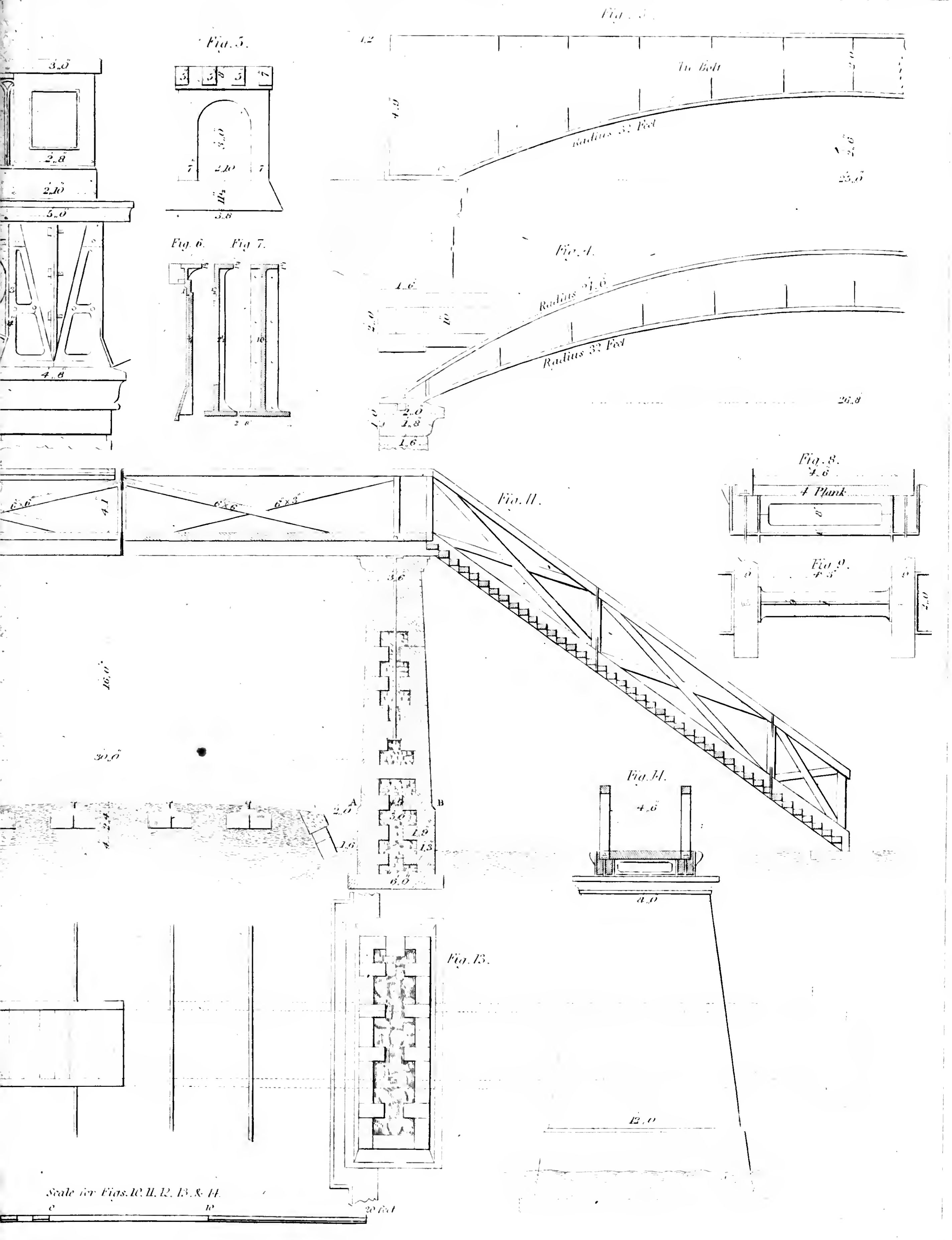




...n Weale, 59, High Holborn, 1845.

B. R. Davi...

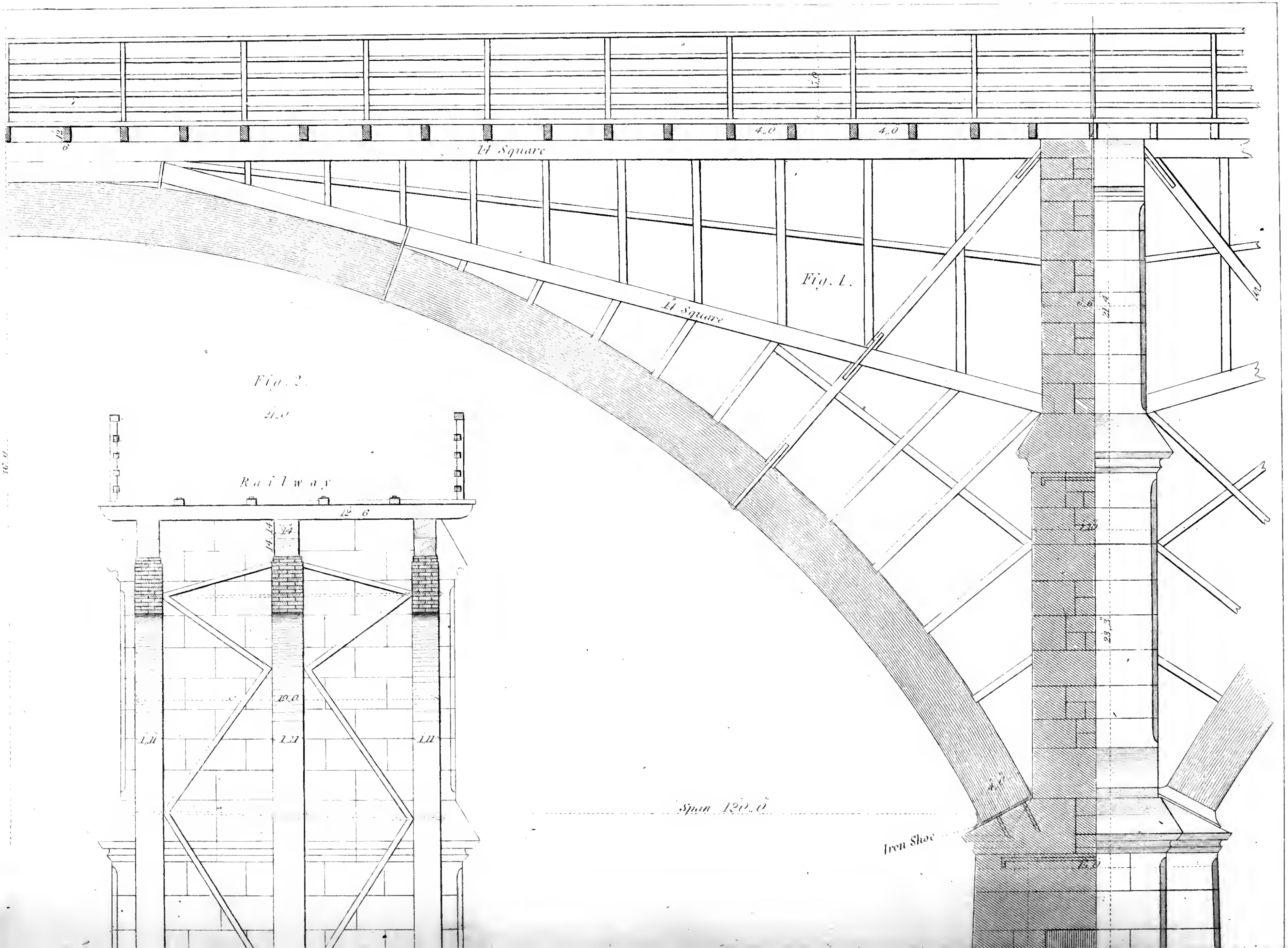
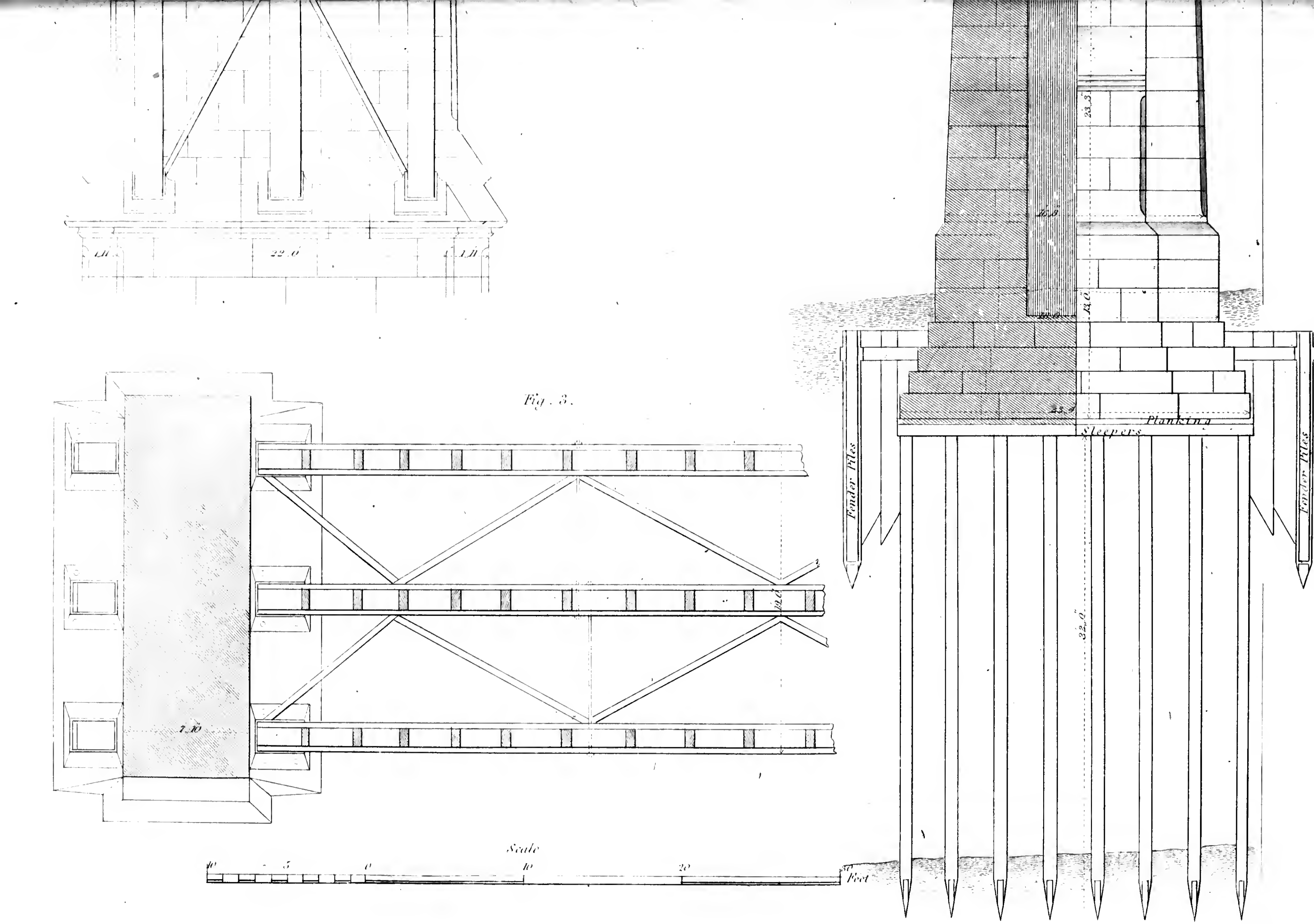


Fig. 1.
Fig. 2.
14 Square
14 Square
4,,0
4,,0
Railway
12 6
21,,0
19,,0
Span 120,,0
Iron Shoe
23,,3
21,,4

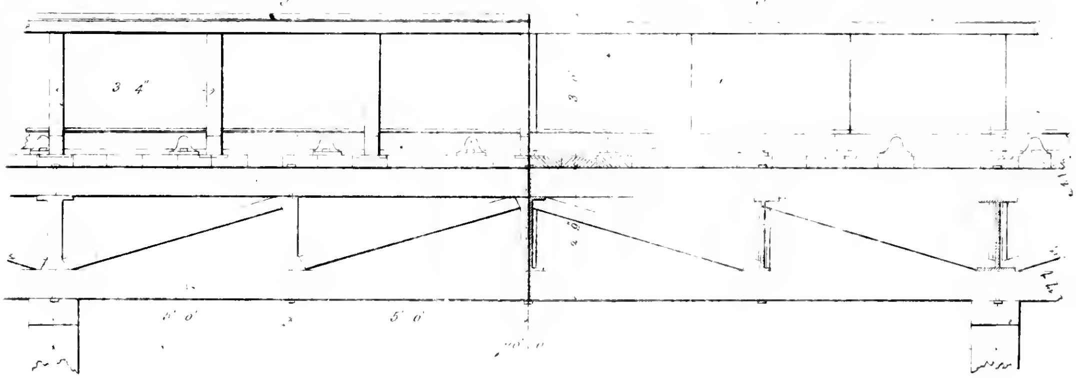


G. Dempsey del.

B. R. Davies fc.

London Published by John Weale, 59 High Holborn 1845.

Fig. 1. *Fig. 2.*



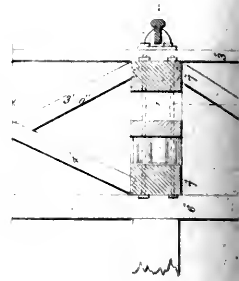
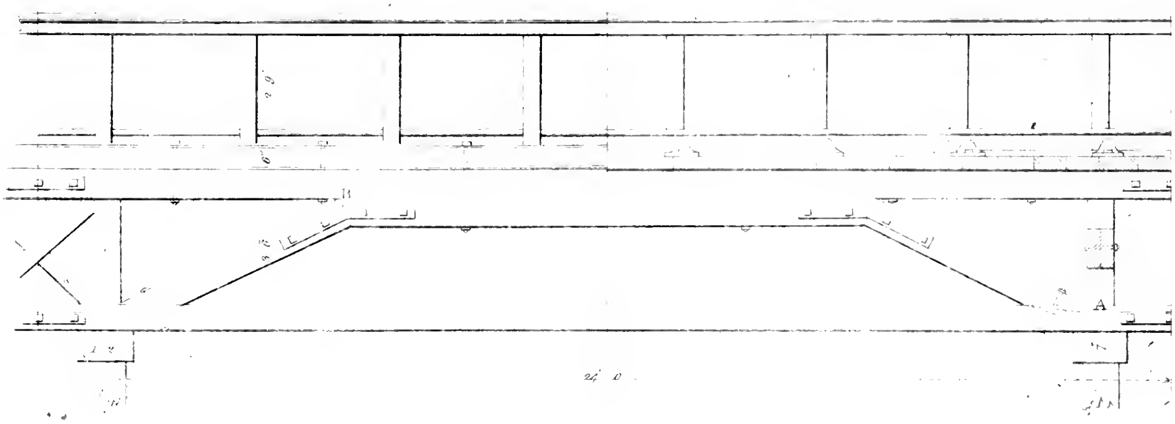
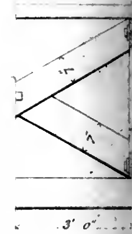


Fig. 4. *Fig. 5.*





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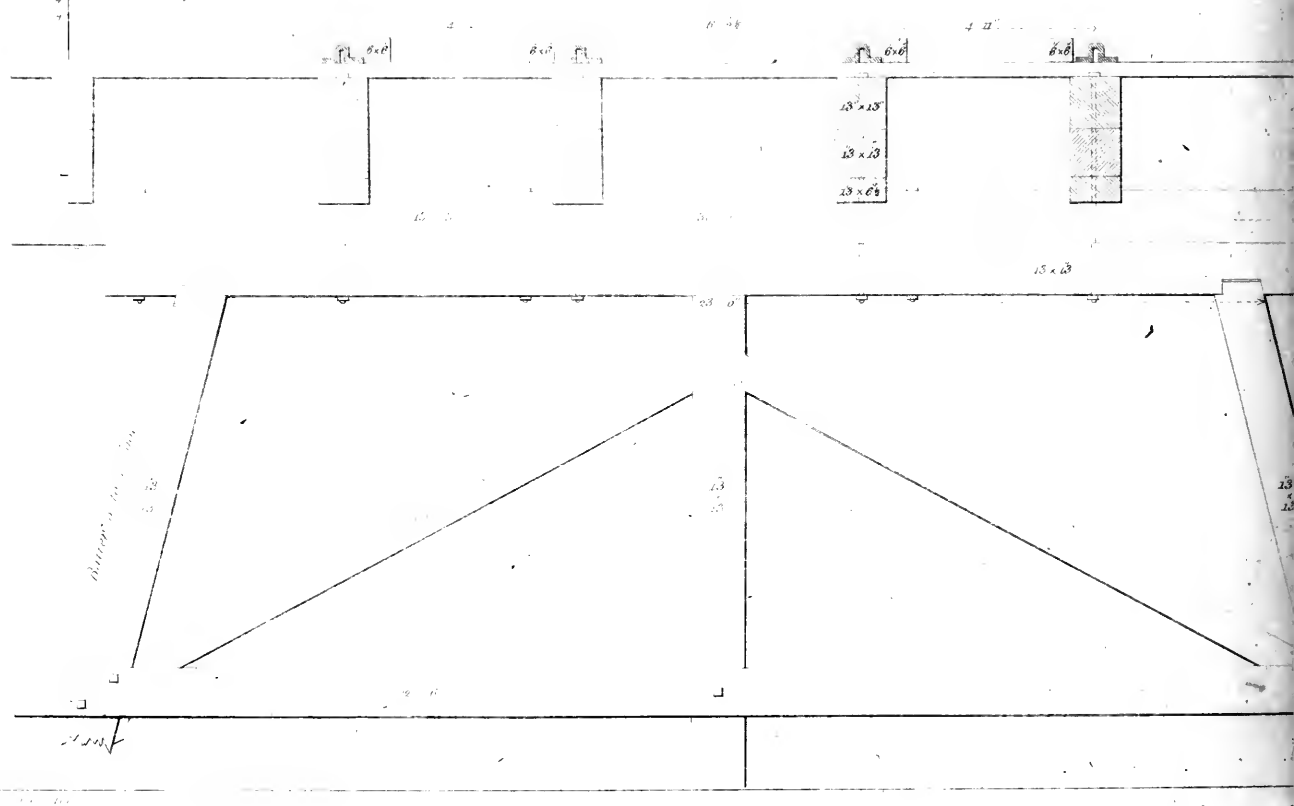
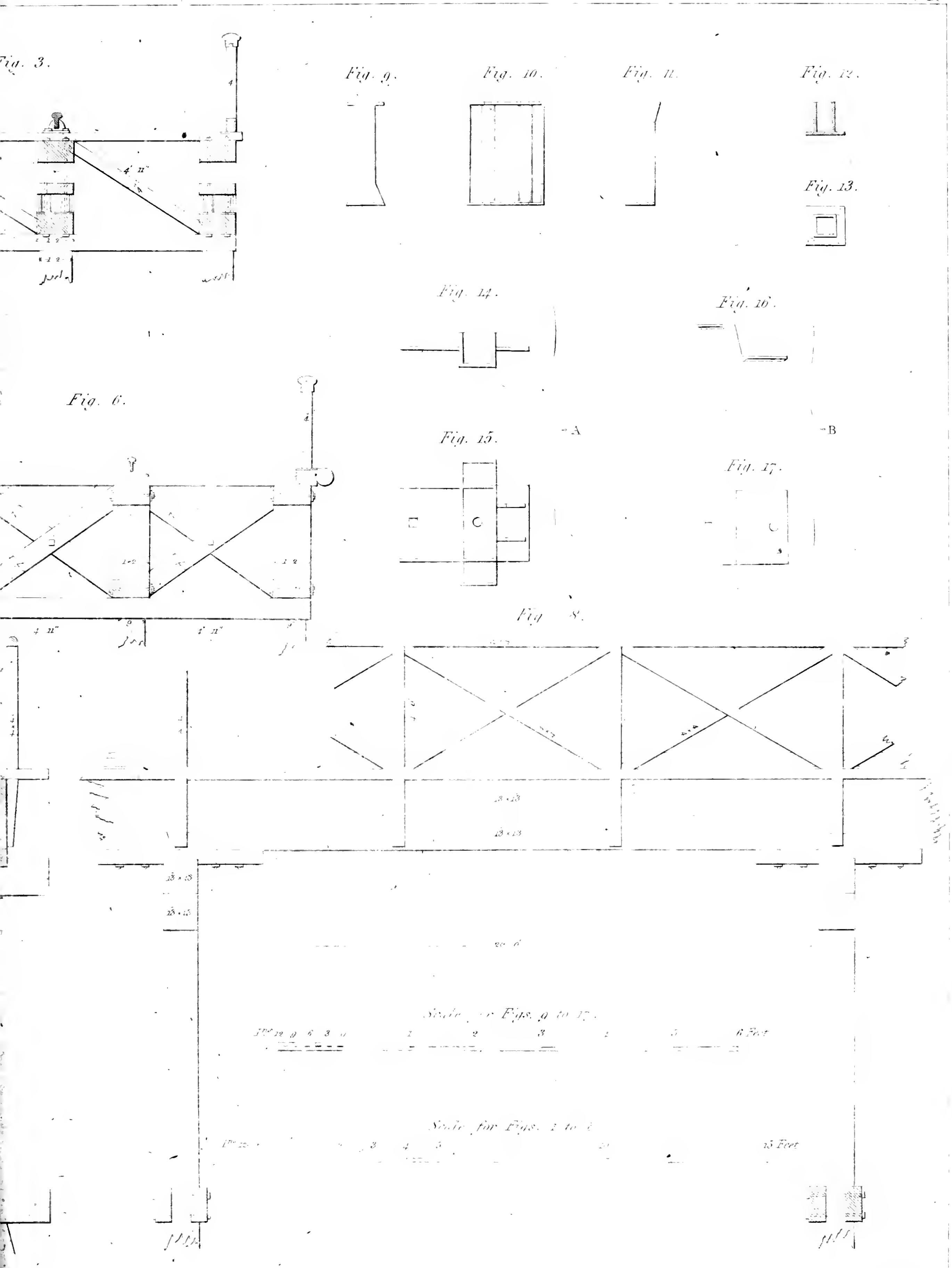


London: Published by



J.B... sc.

...ale, 59, High Holborn. 1845.

Fig 1

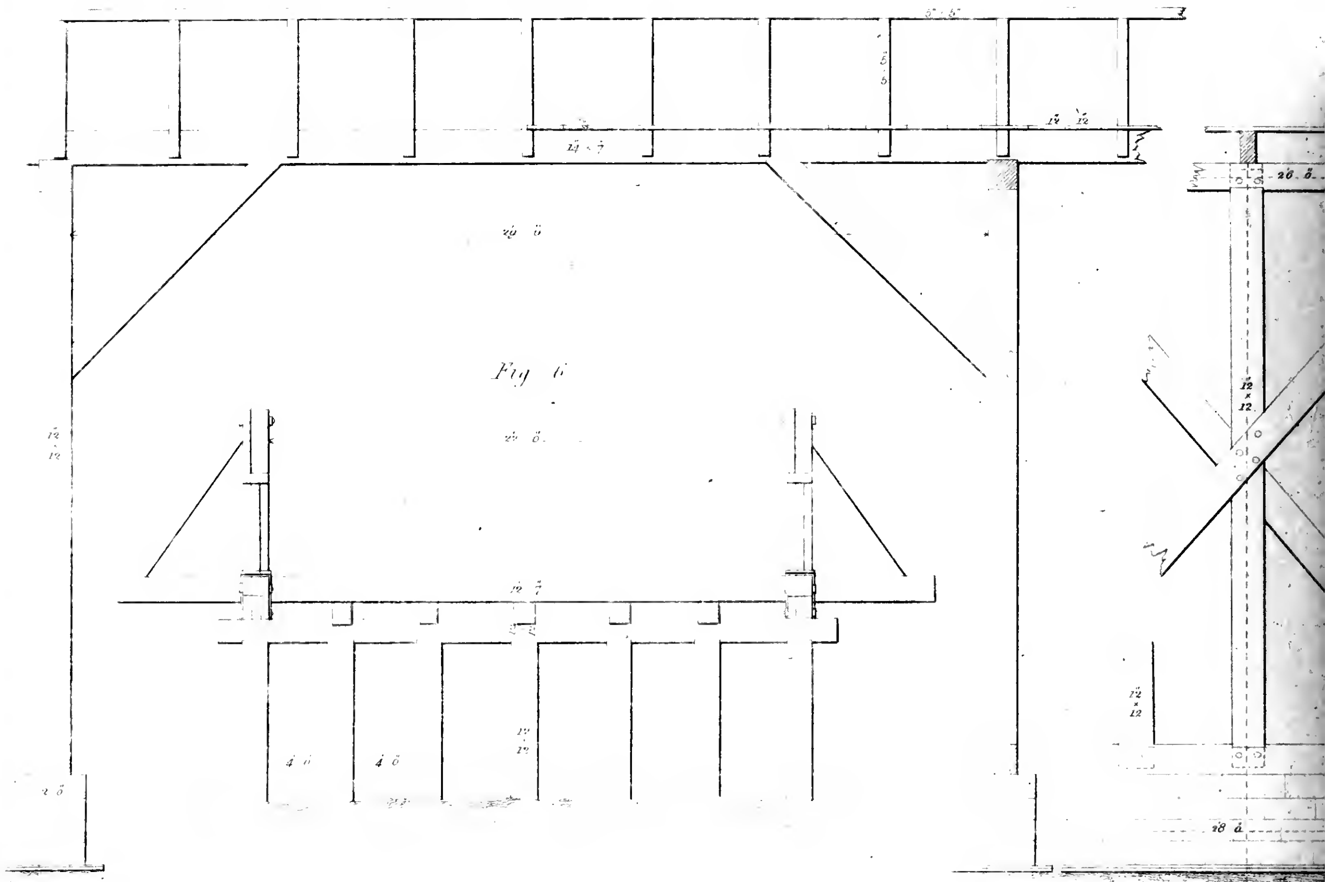
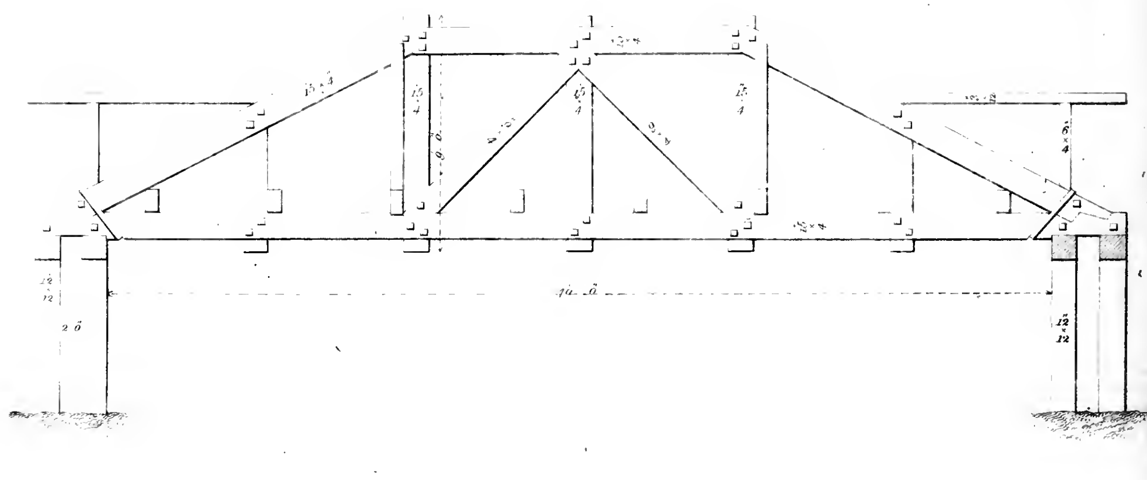


Fig. 5

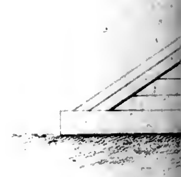


Scale for Figs. 1 2 3 & 4

0 5 10 20 30 Feet

Scale for Figs 5 6 7 & 8.

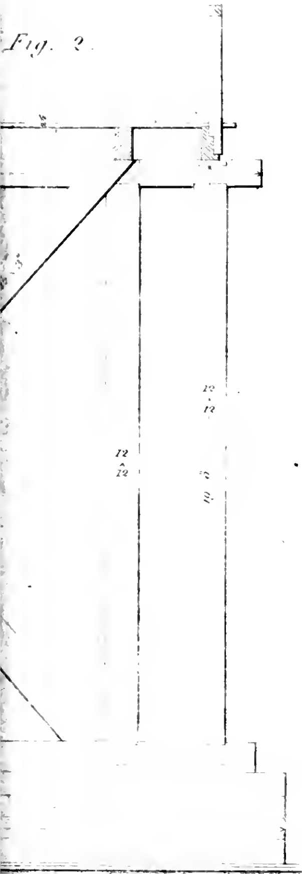
0 5 10 20 30 40 Feet



del

London, Published by

Fig. 2.



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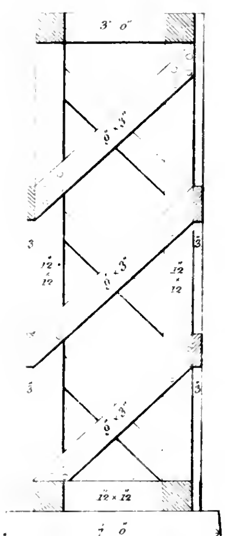
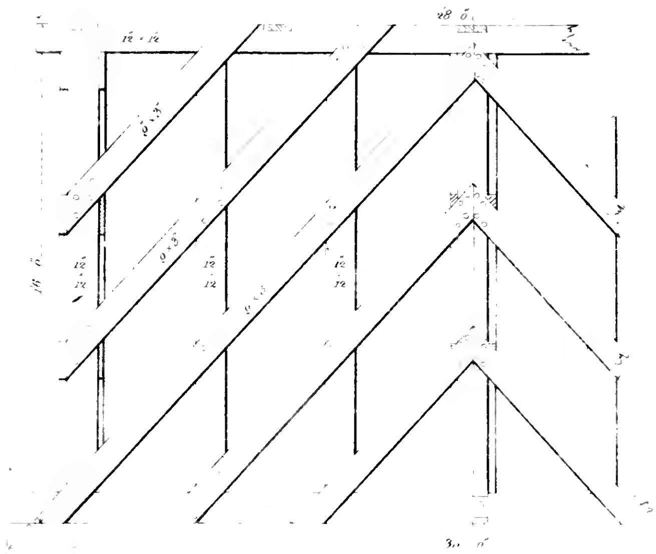
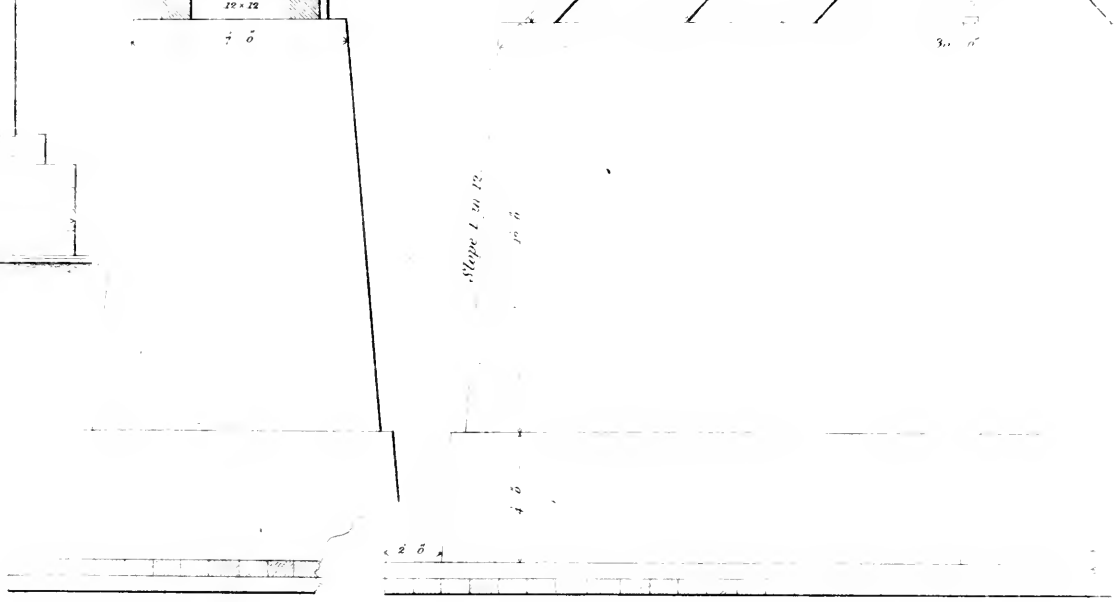


Fig. 4.





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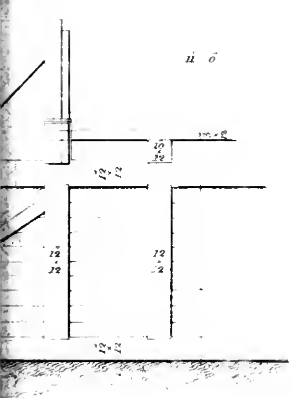

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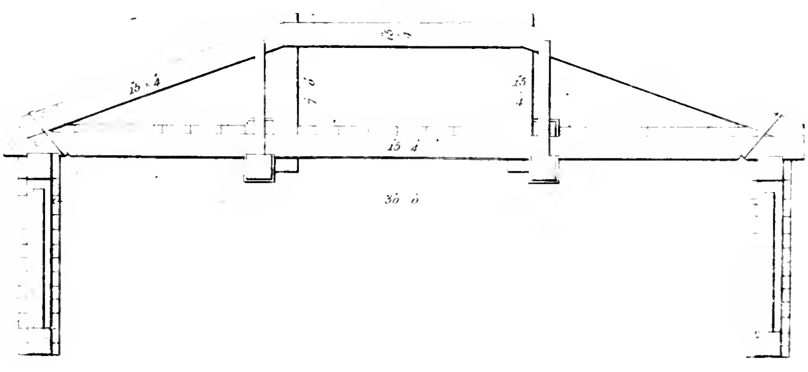

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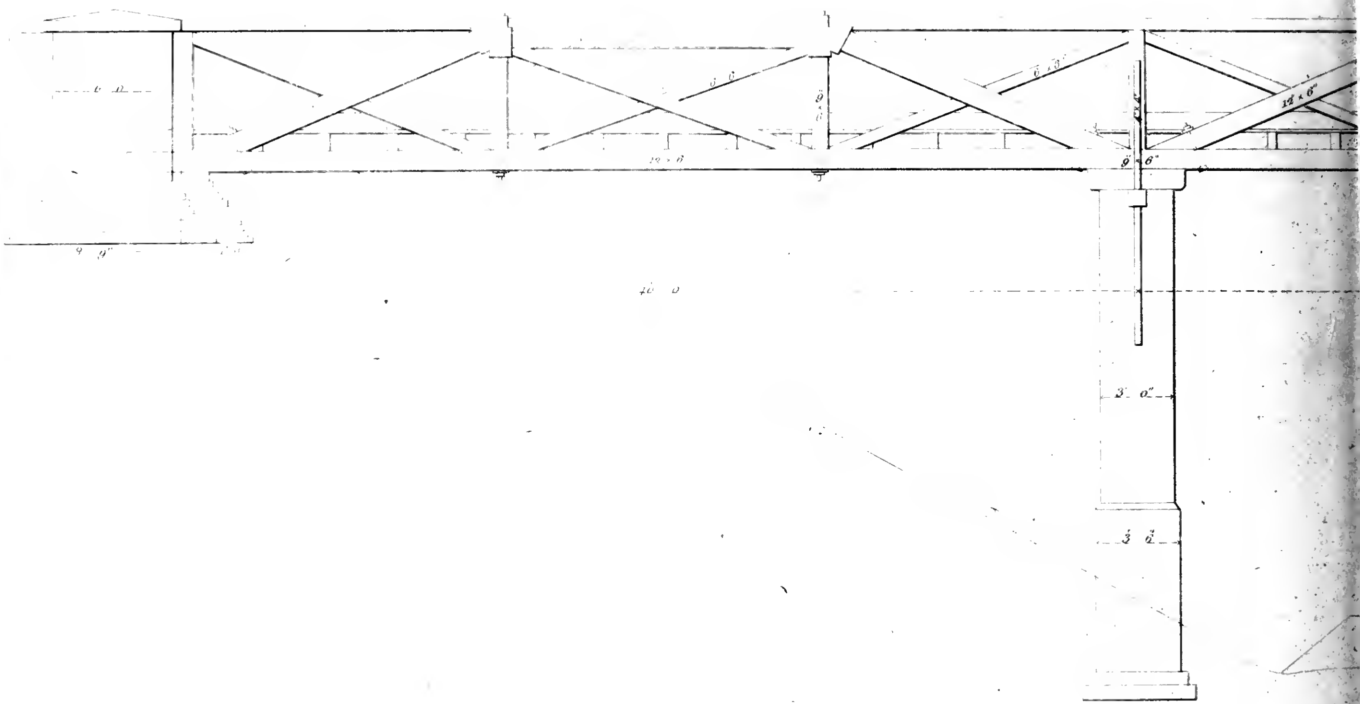

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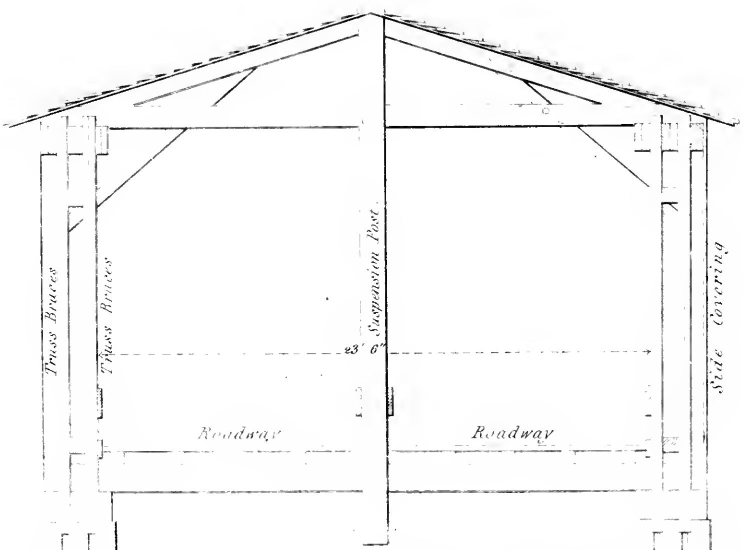

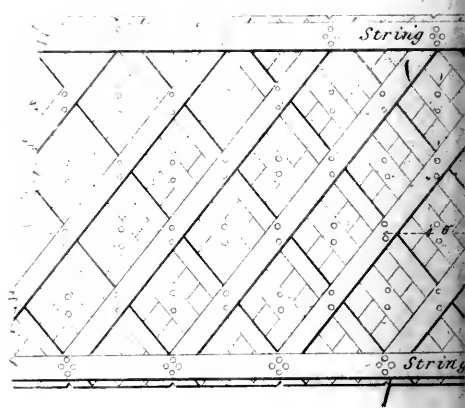

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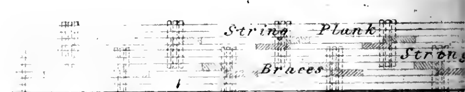

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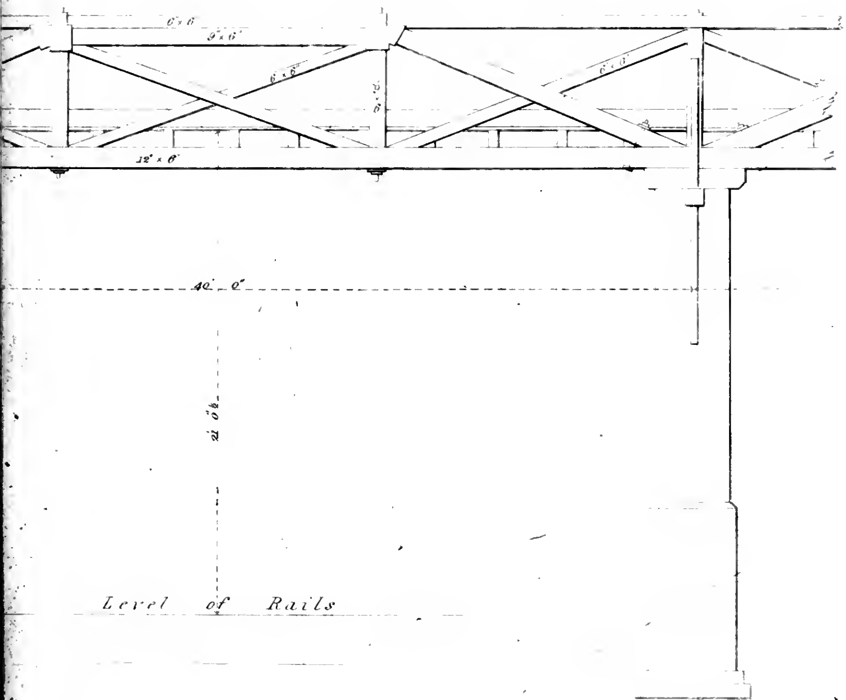

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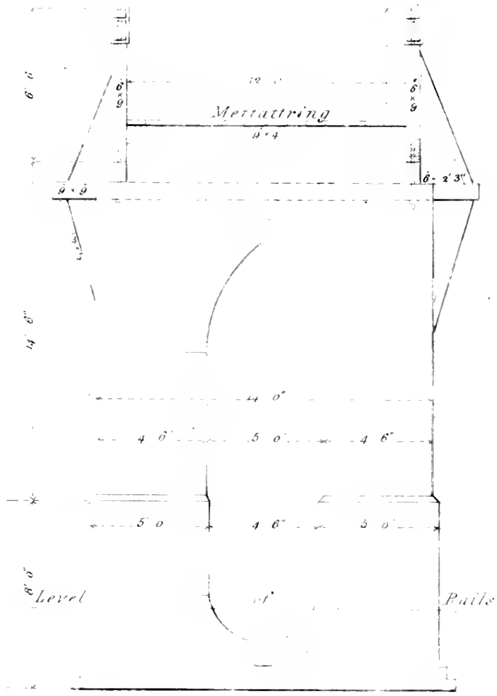

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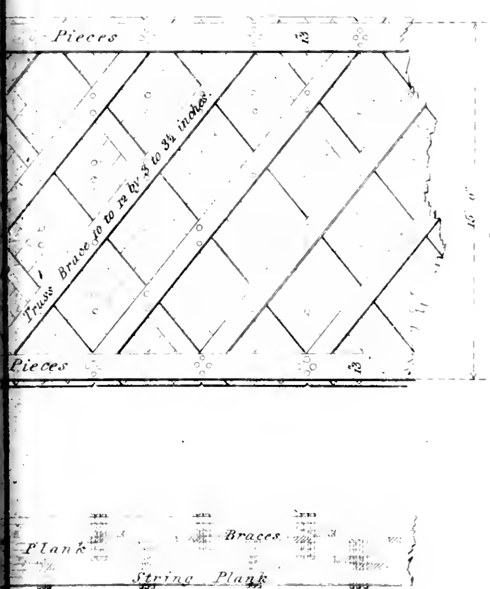

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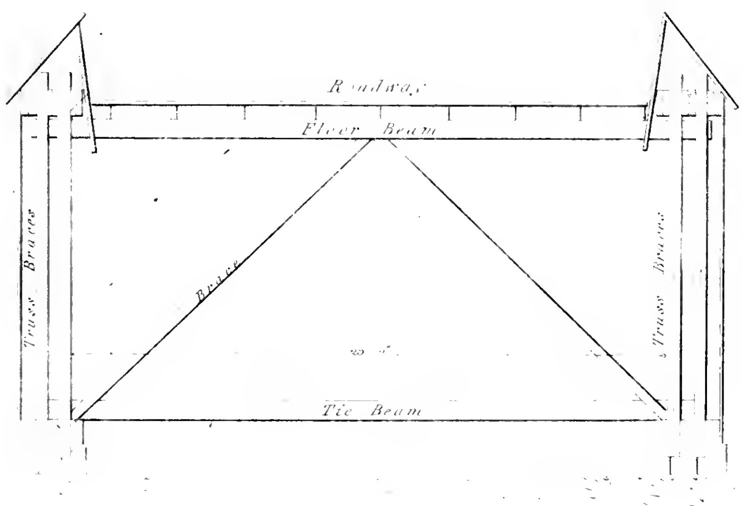
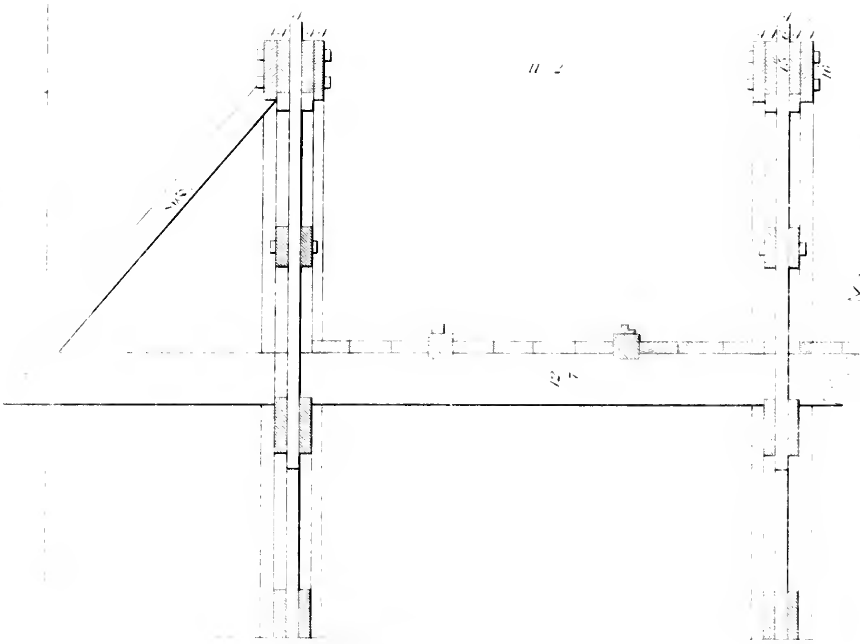
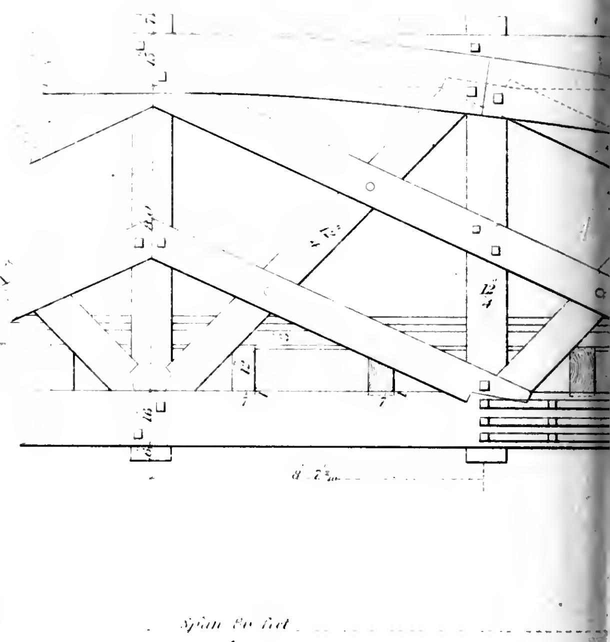
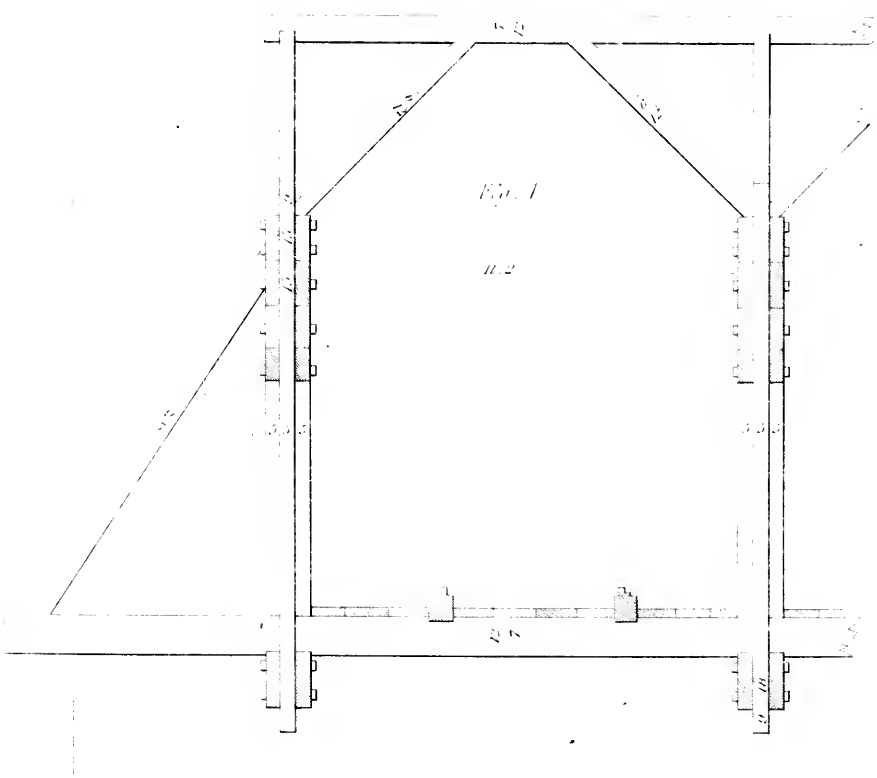


Scale

Fig. 2







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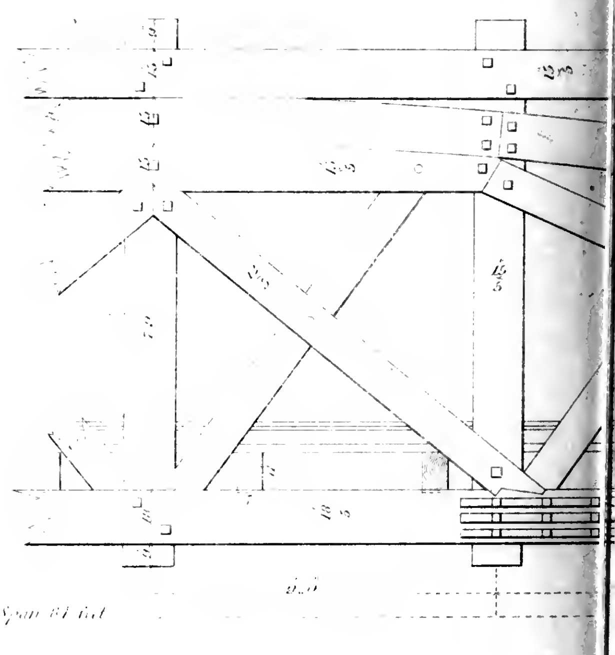

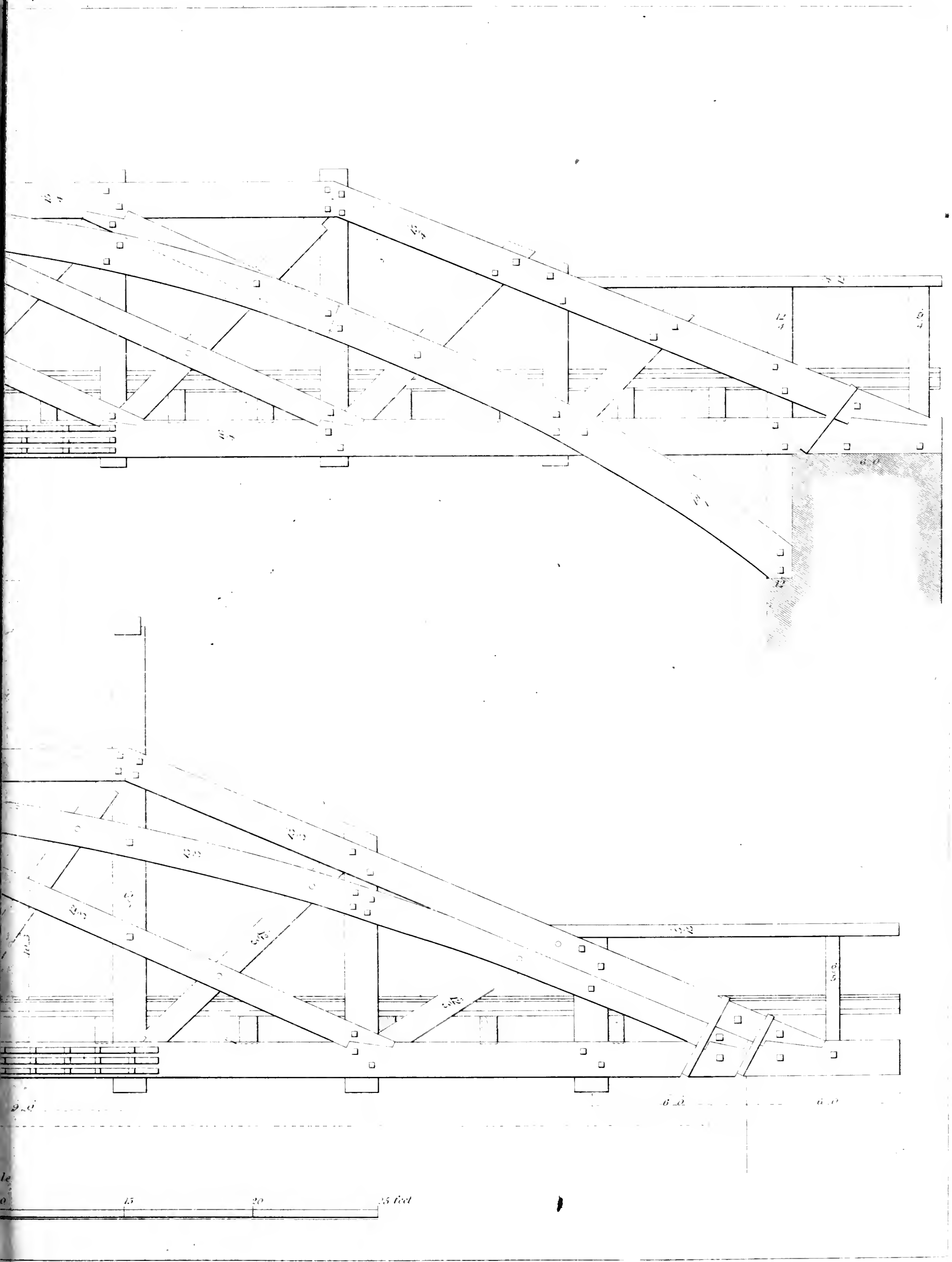

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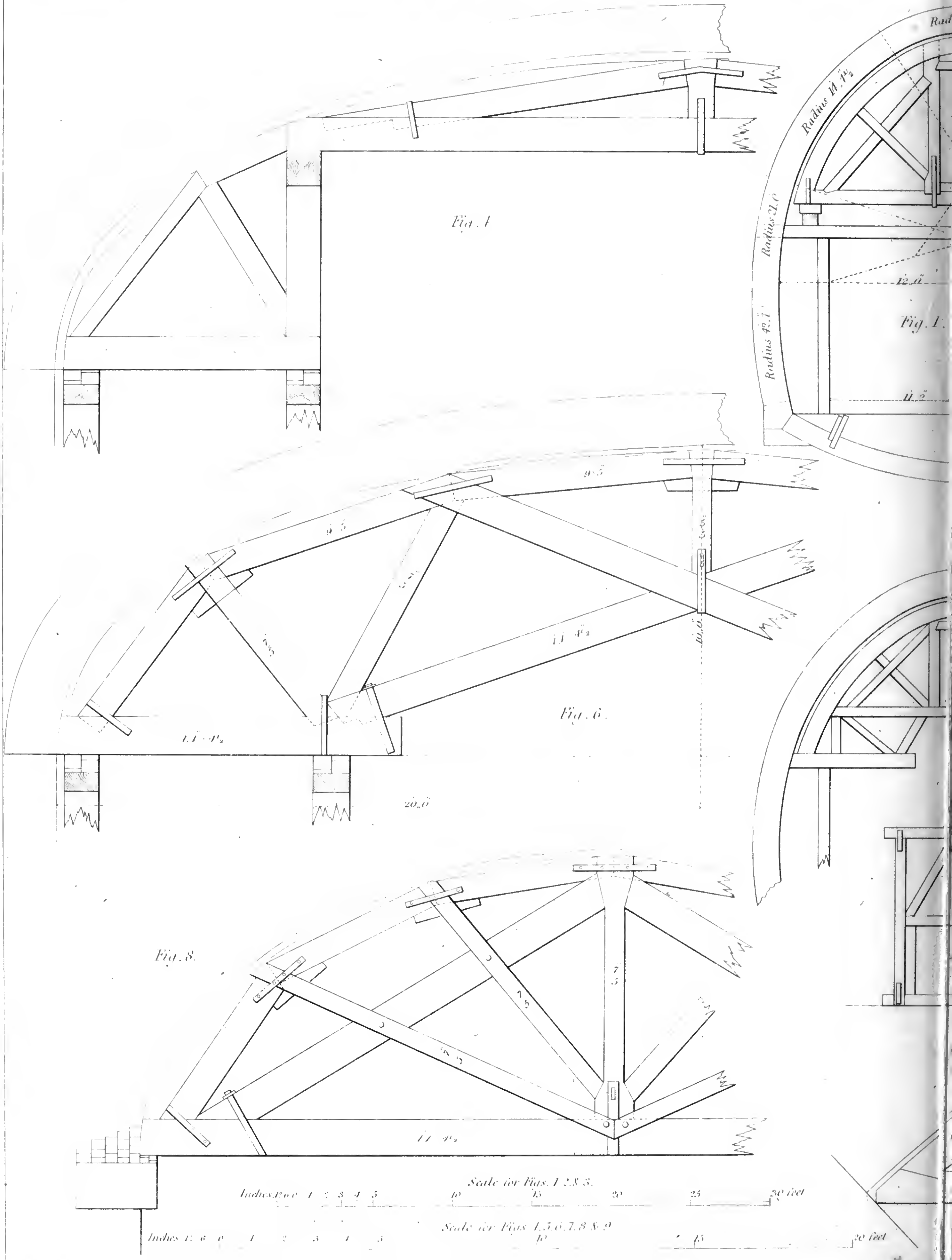

Fig. 1
Radius 14. 4½
Radius 21. 0
Radius 42. 1
12. 0
11. 2
Fig. 1.
Fig. 6.
9. 5
6. 5
7 ½
11. 4½
10. 0
1. 1. 4½
20. 0
Fig. 8.
7 5
11. 4½
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Inches 12 6 0 1 2 3 4 5 10 15 20 25 30 feet
Scale for Figs. 1. 5. 6. 7. 8 & 9
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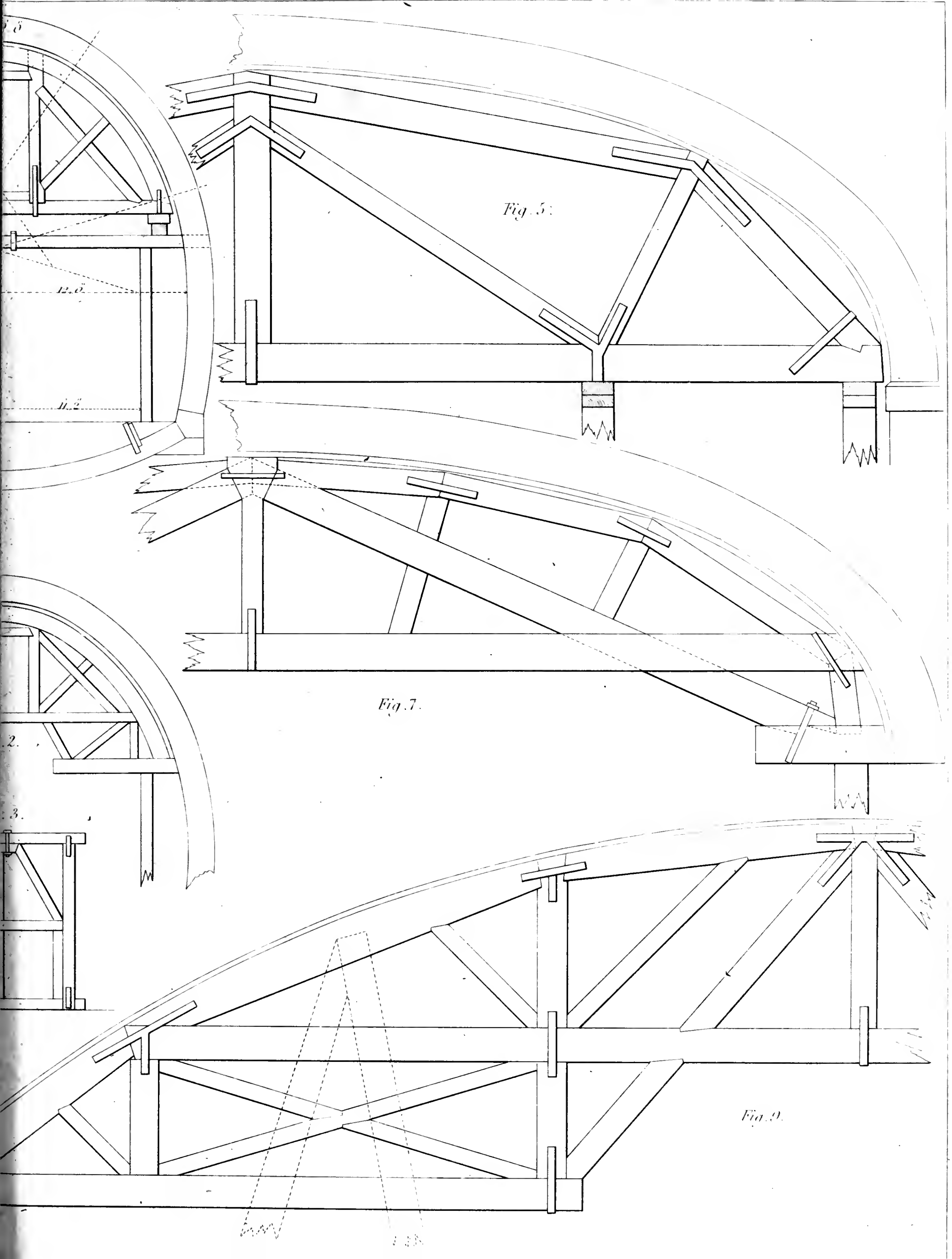
Fig. 5.
12.6
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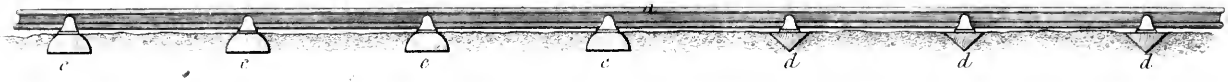
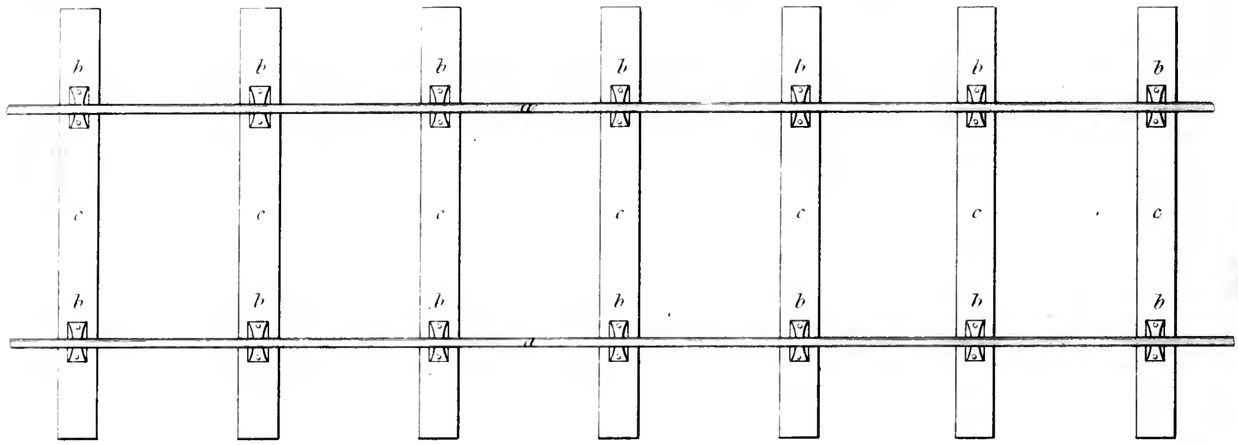
Fig. 9.

Fig. 9.





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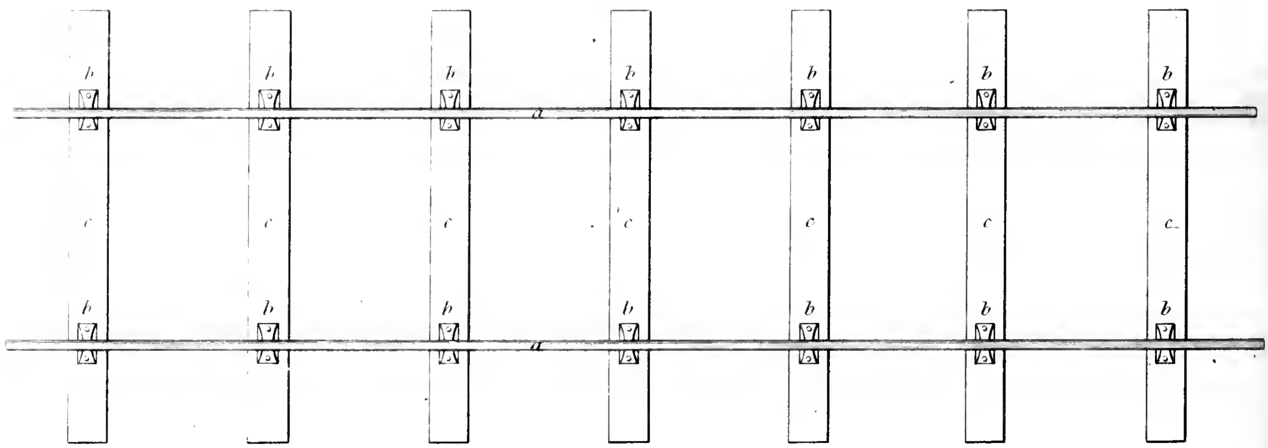
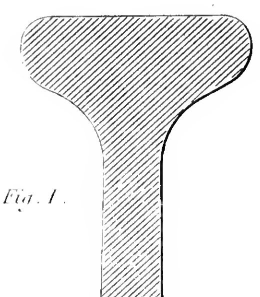


Fig. 1.



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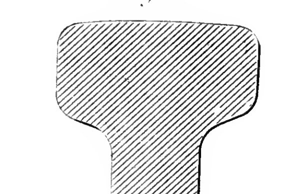

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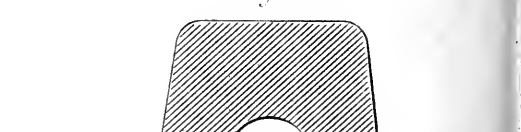

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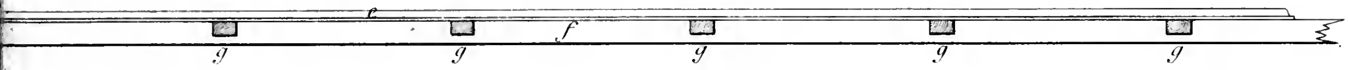

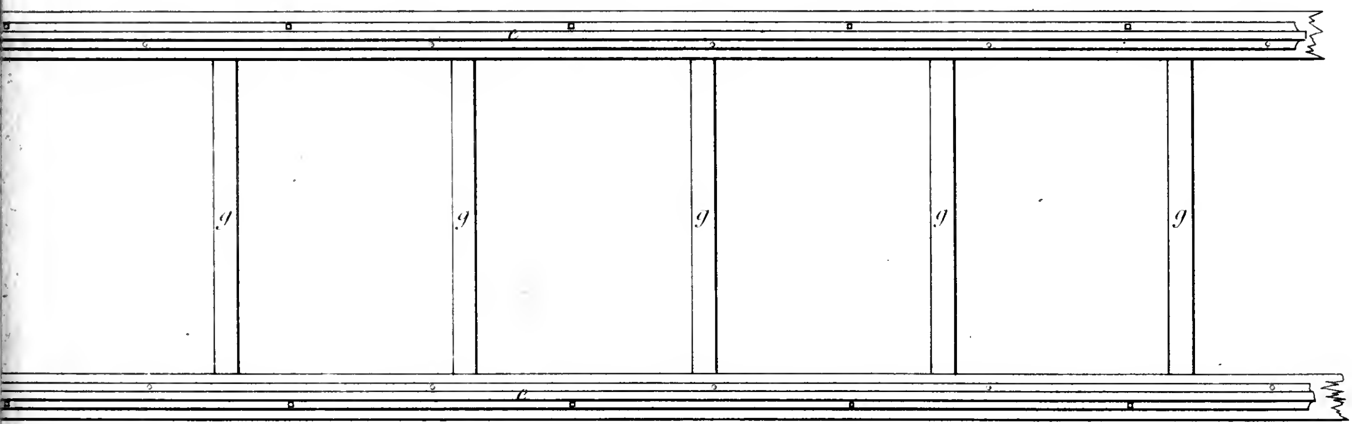

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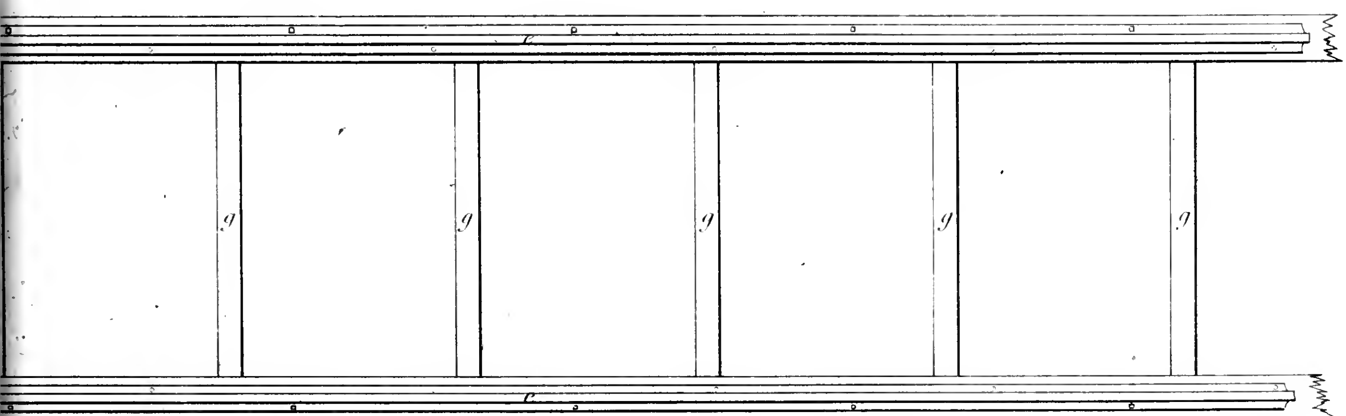

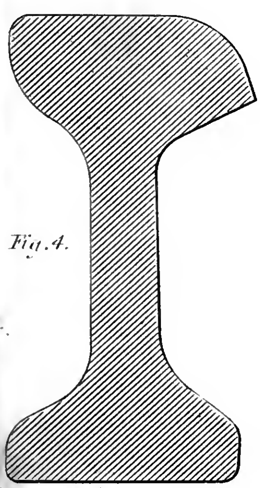

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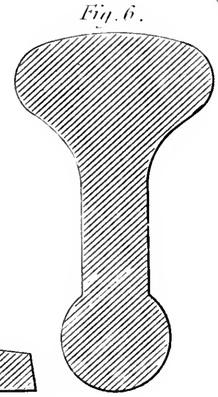
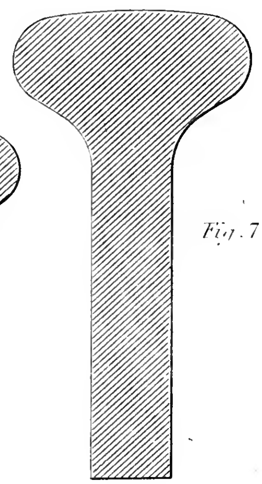
Fig. 6.





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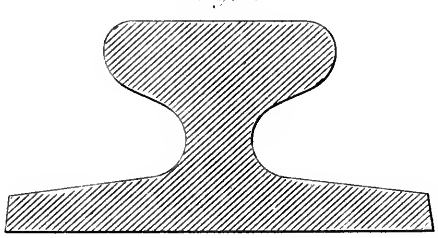

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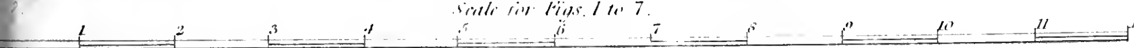

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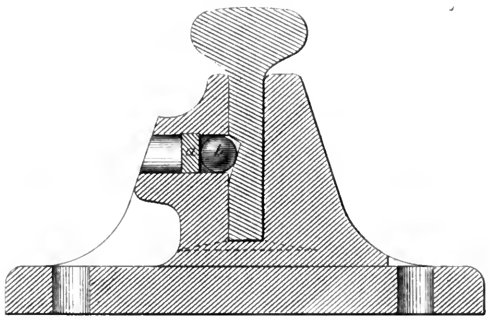

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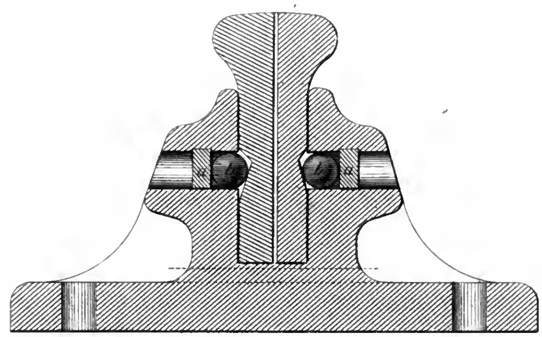

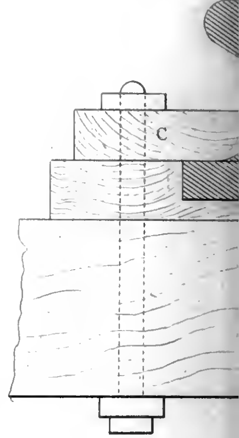

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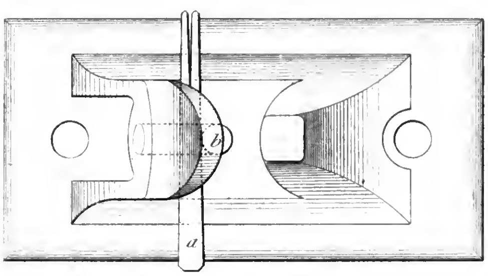

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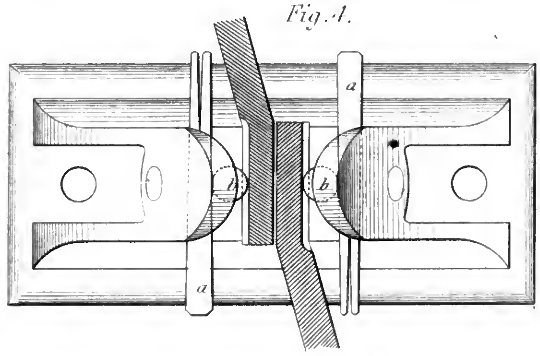

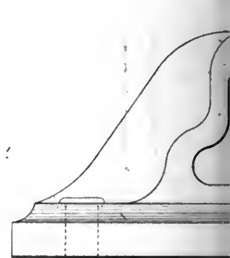

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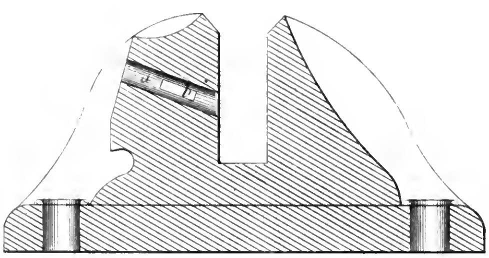

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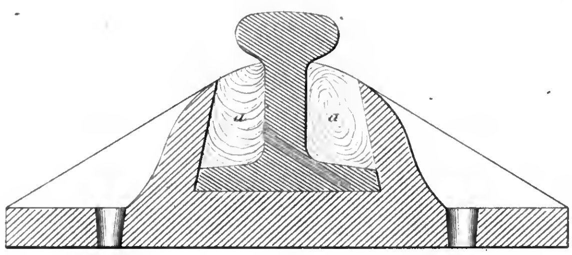

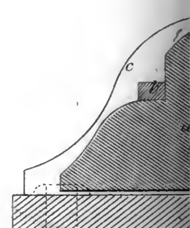

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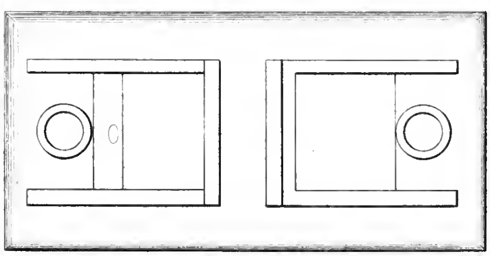

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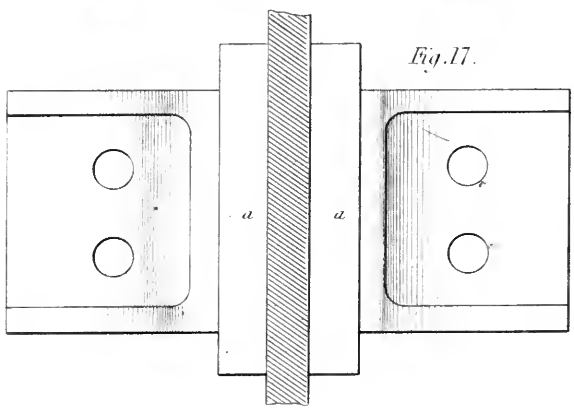

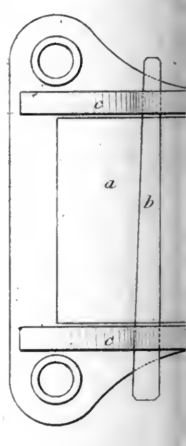

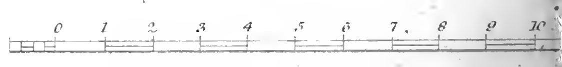

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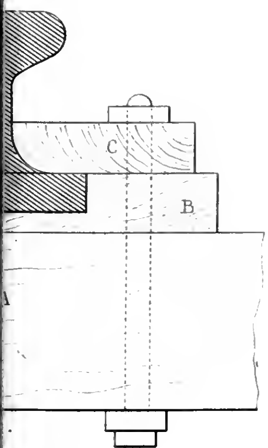

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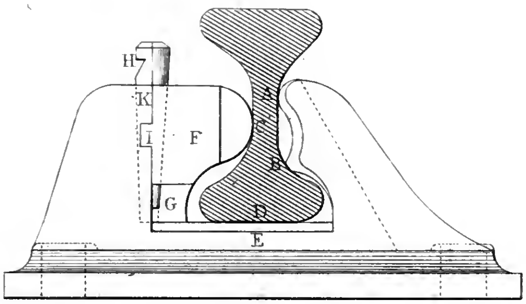

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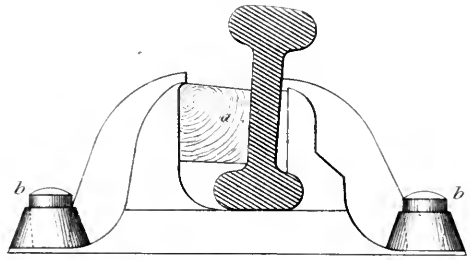

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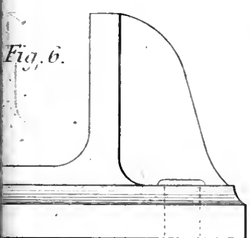

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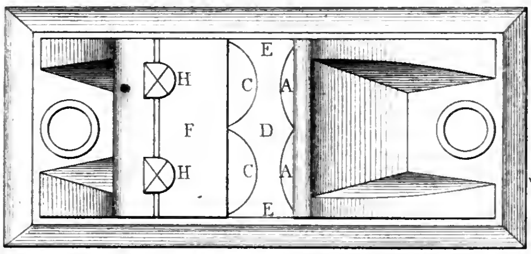

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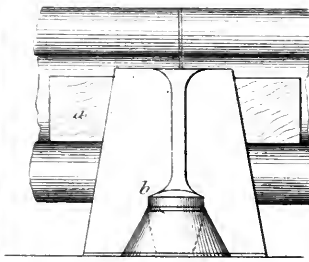

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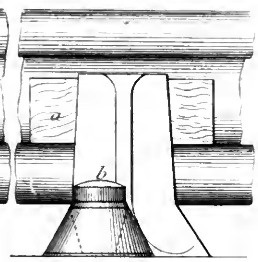

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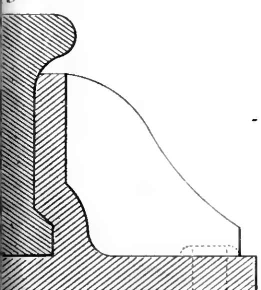

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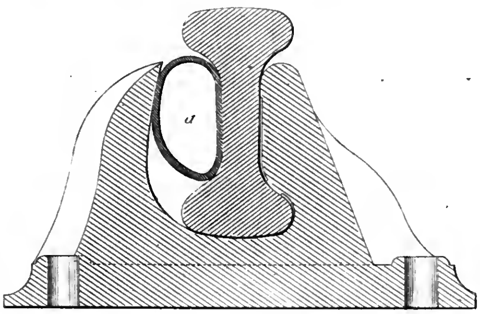

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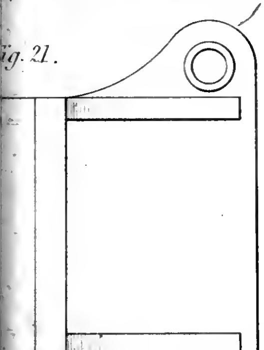

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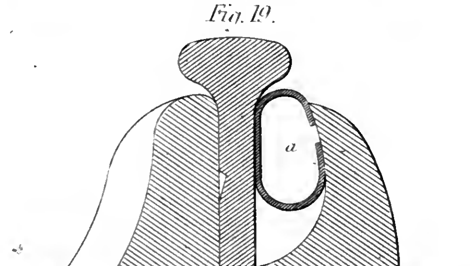

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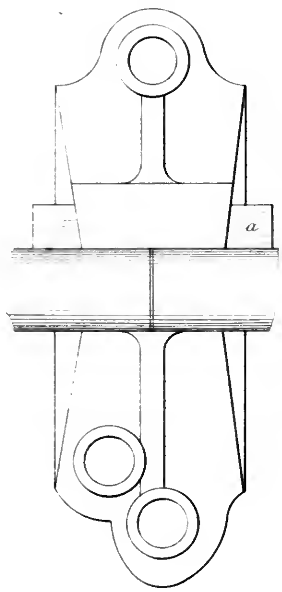

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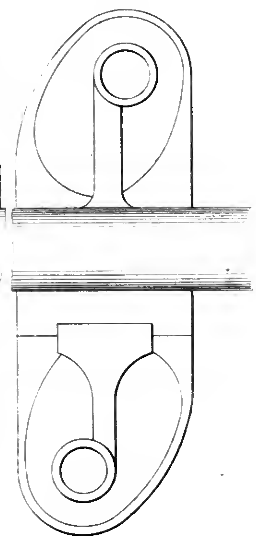

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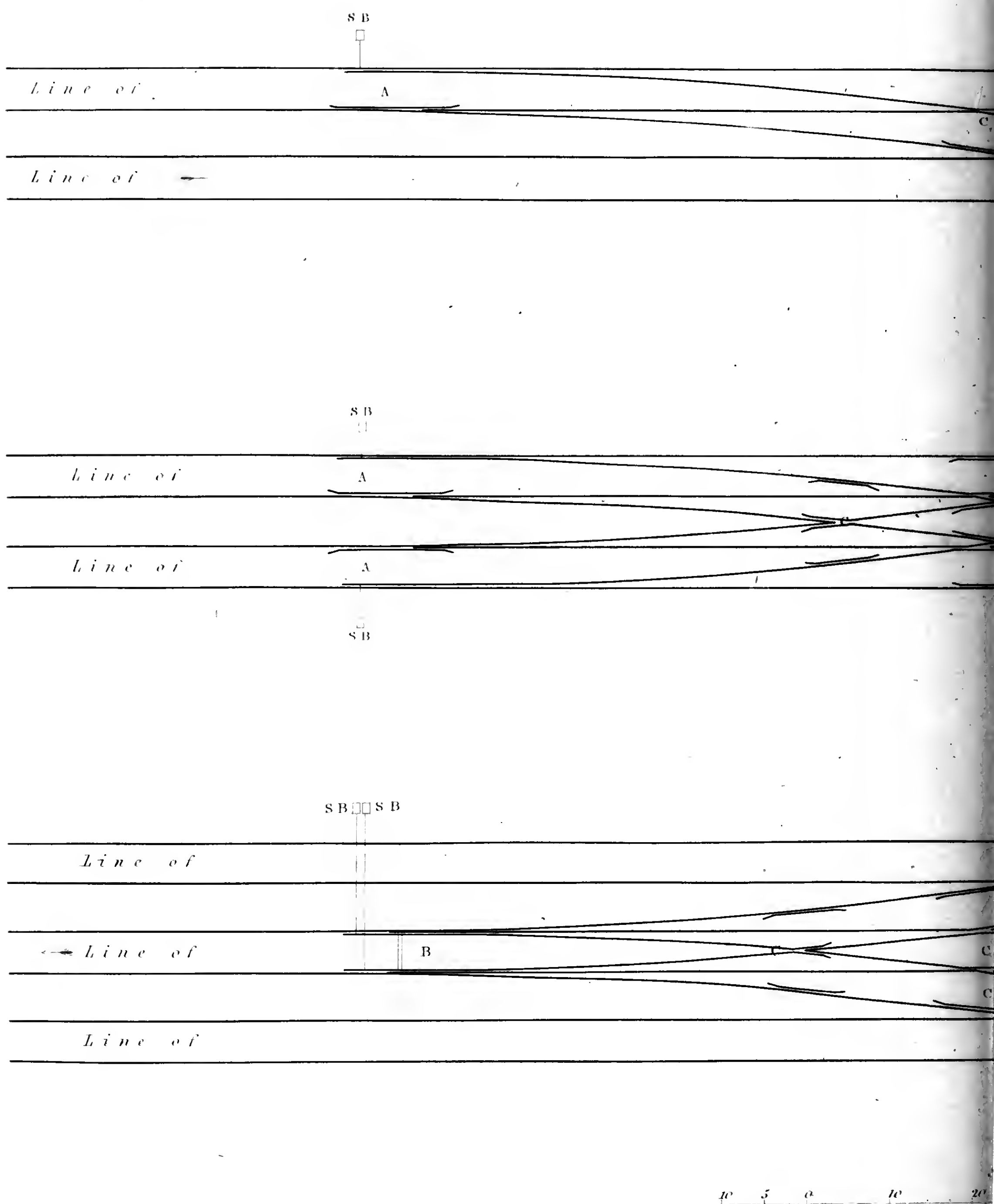

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Plans

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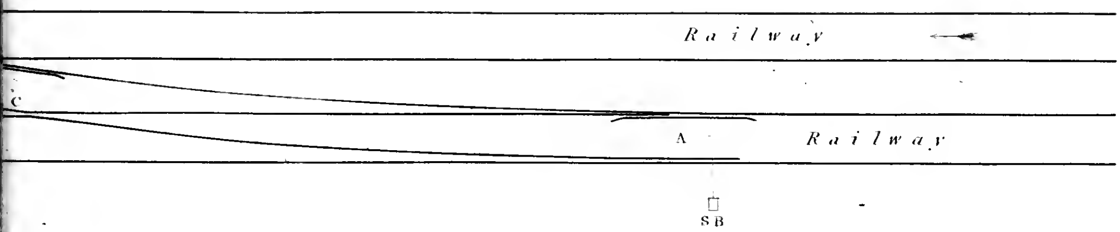

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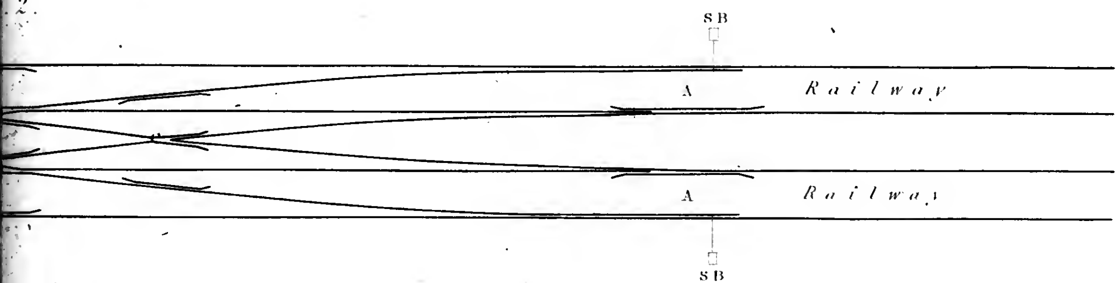

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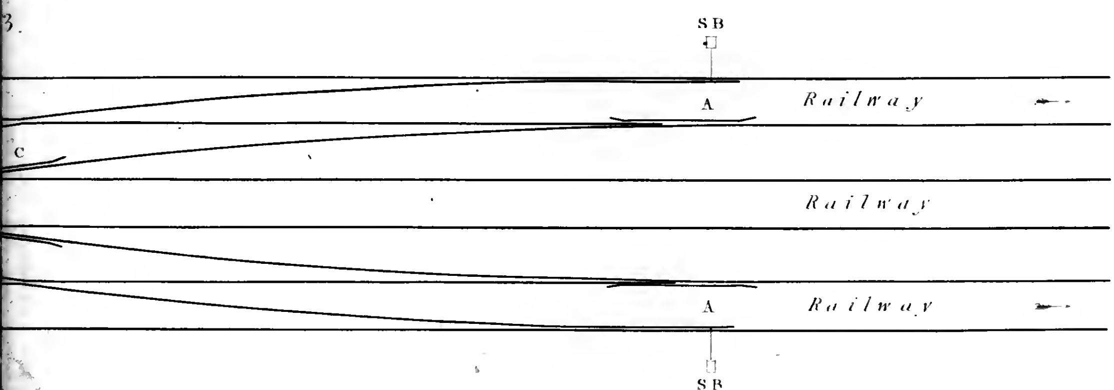

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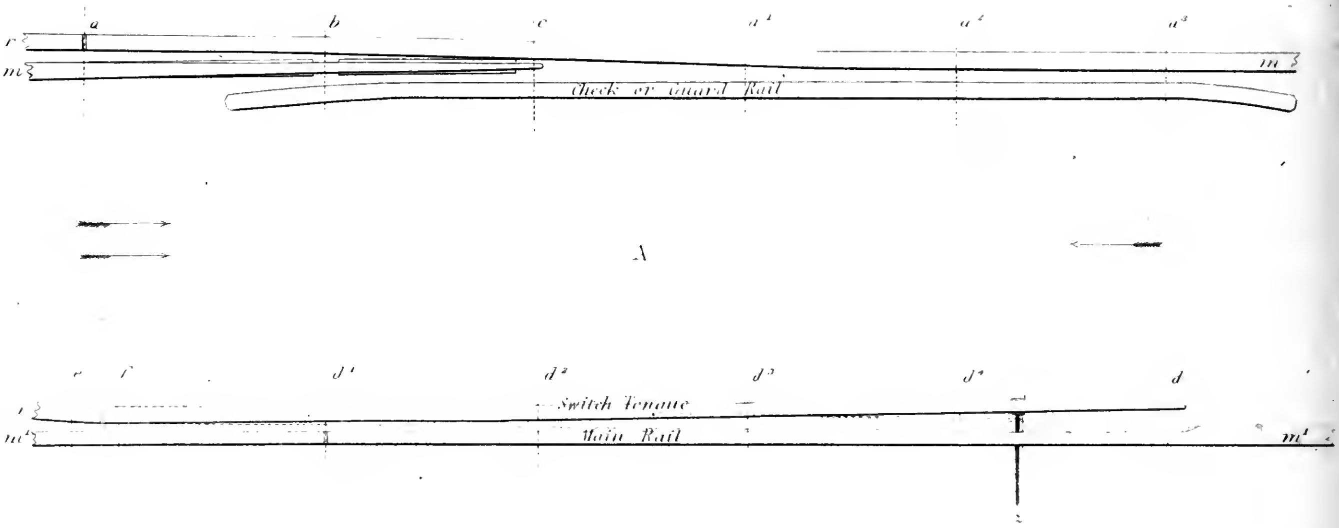

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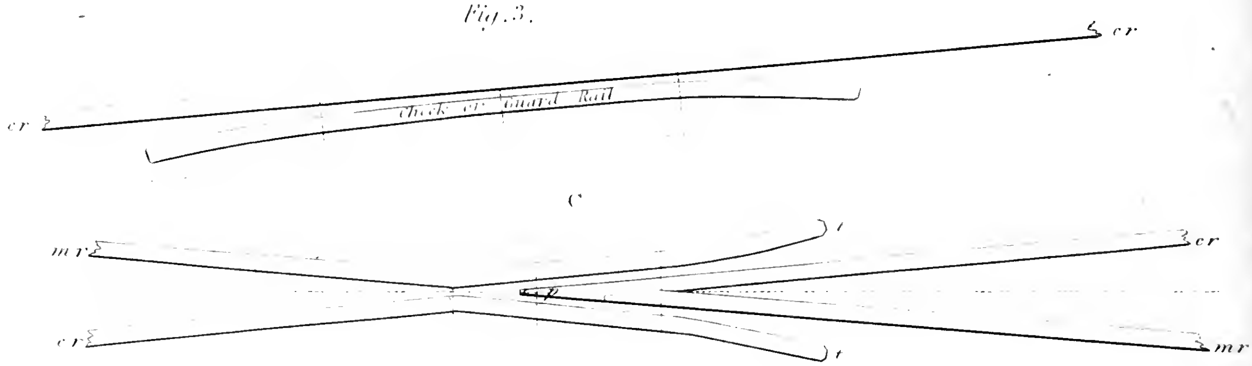

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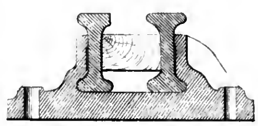

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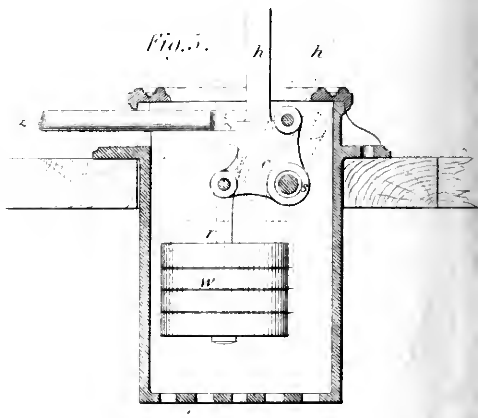

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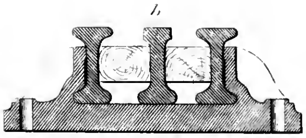

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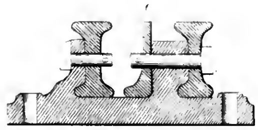

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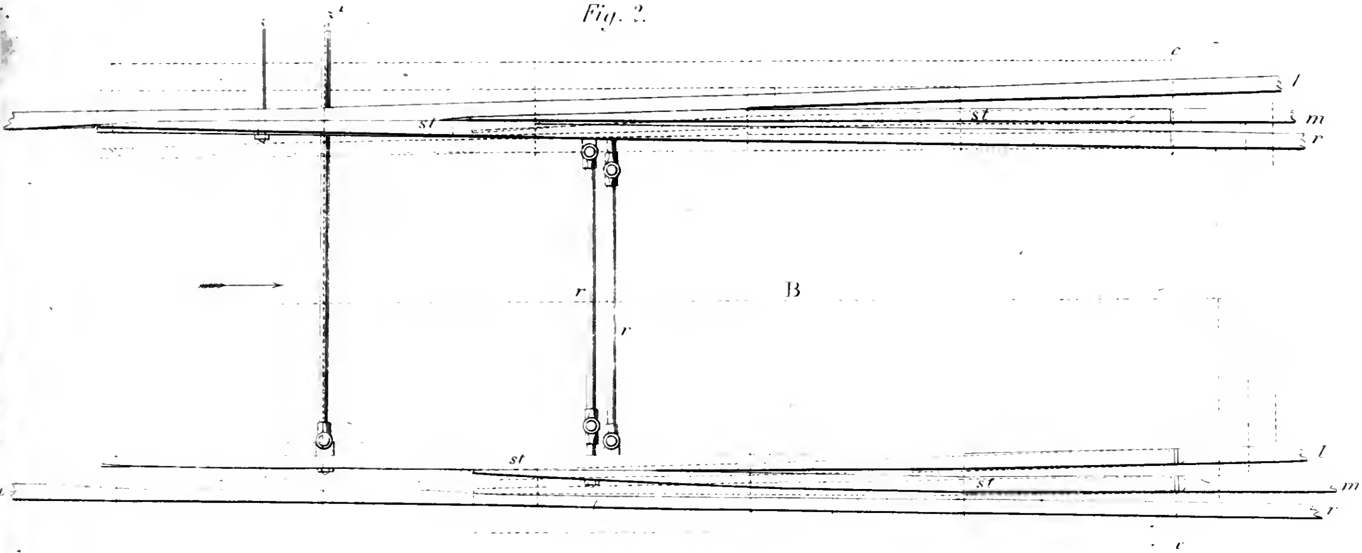
Fig. 2.



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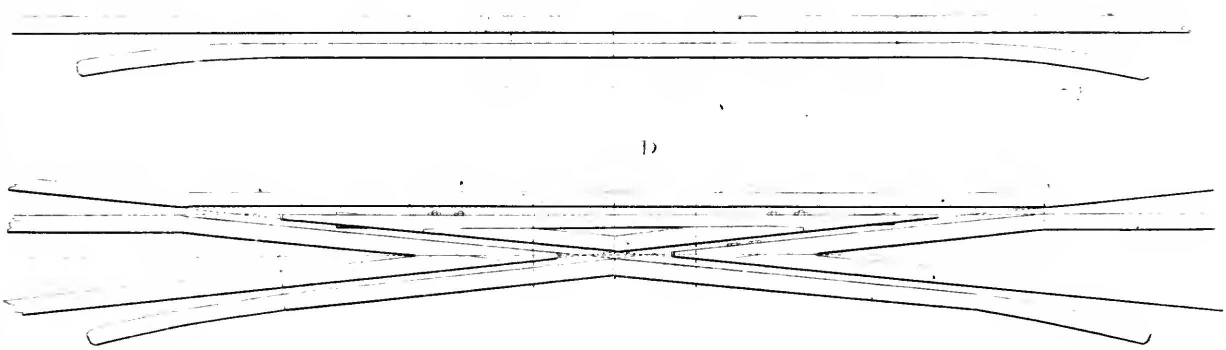


Fig. 6.

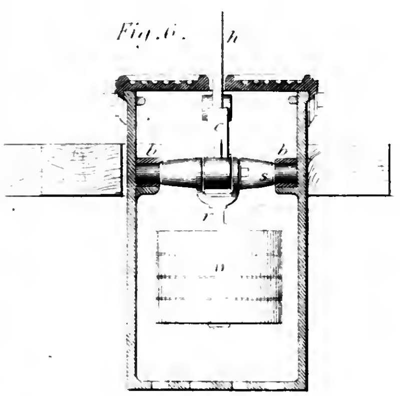
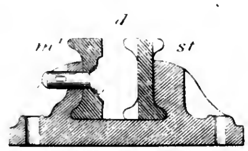
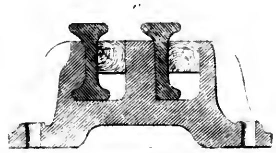


Fig. 10.



B

Fig. 11



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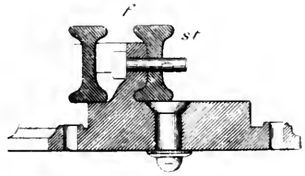


8, 3, 5, 1.

5 6 7 8 9 feet

8, 9, 10, 11 & 12.

2 1 feet

Fig. 1.

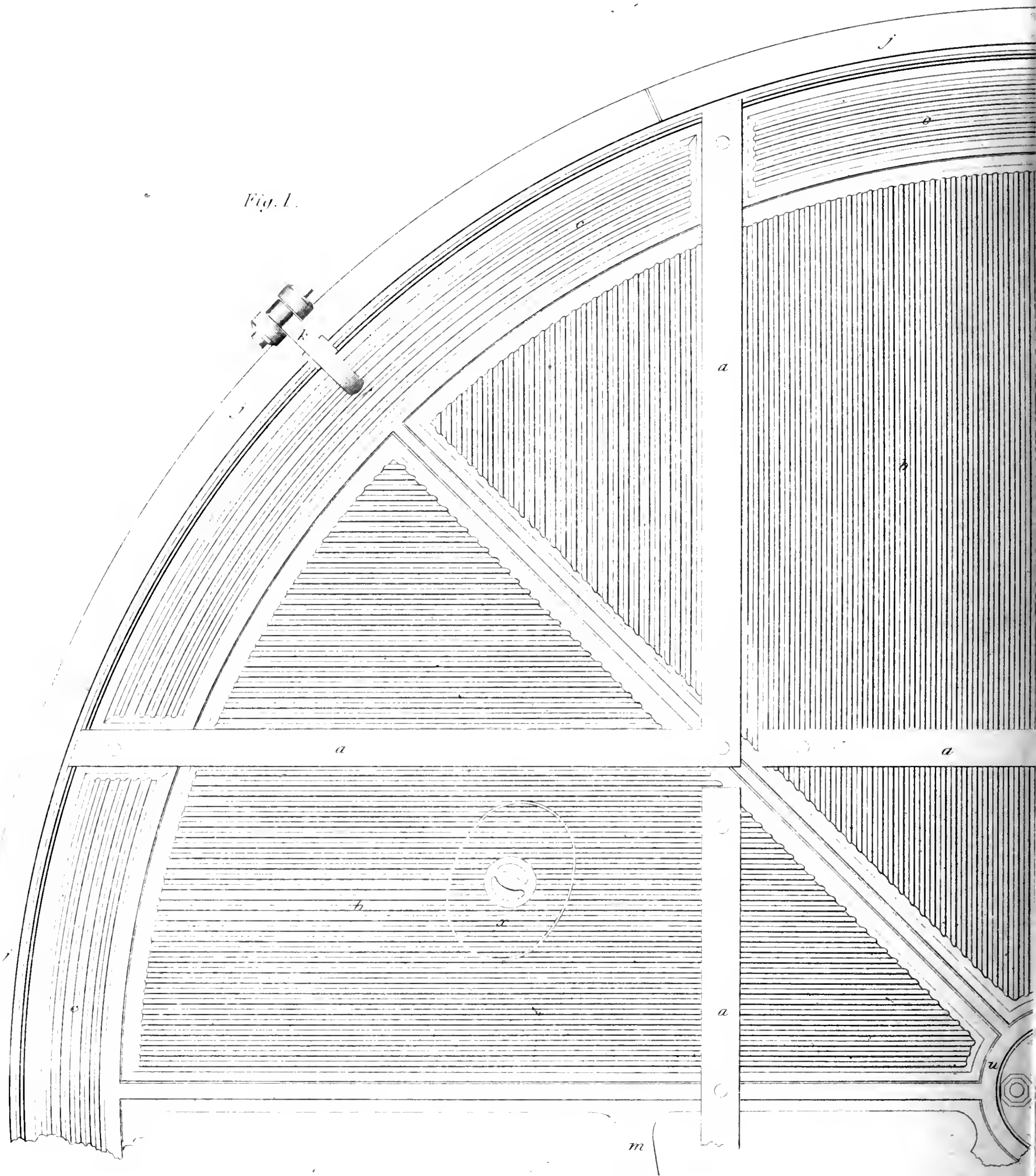
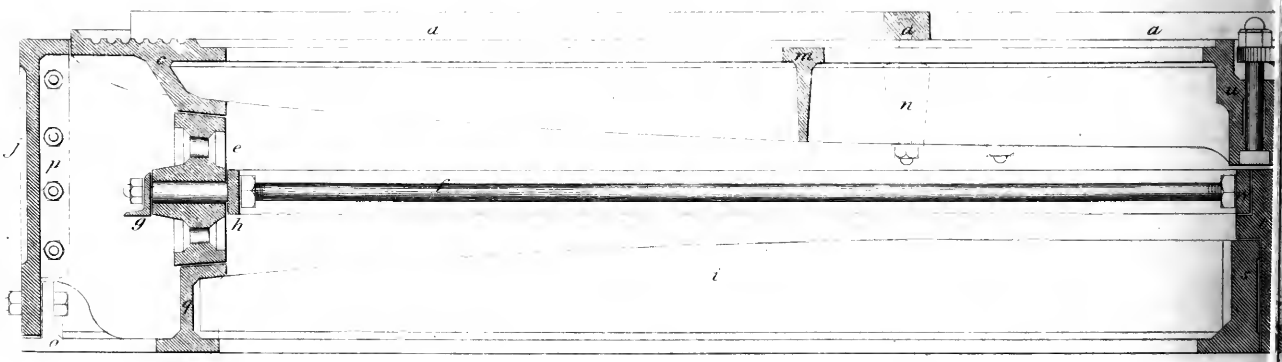


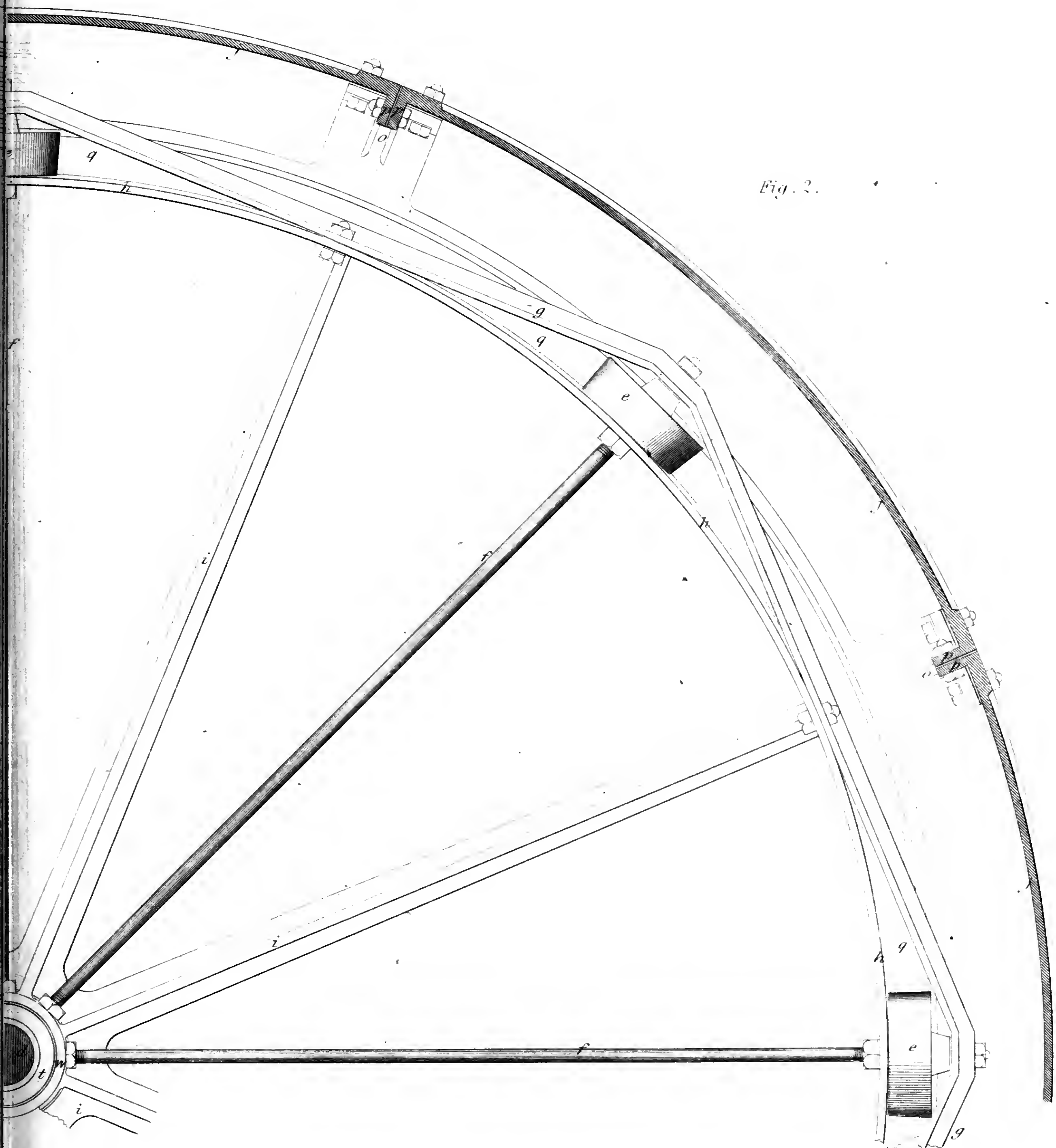
Fig. 3.



Scale

Inches 12 9 6 3 0 1

G. D. Dempsey del.



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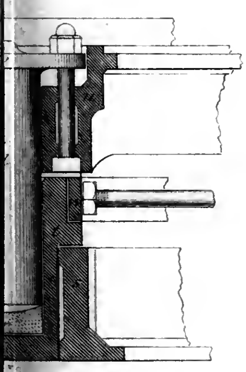


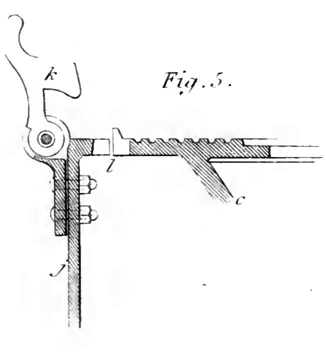
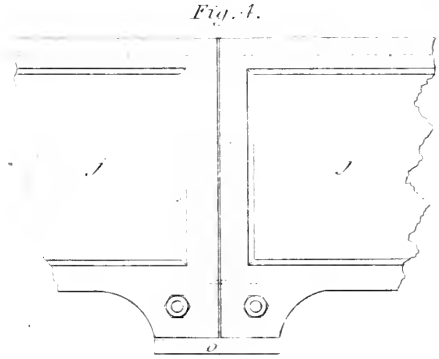
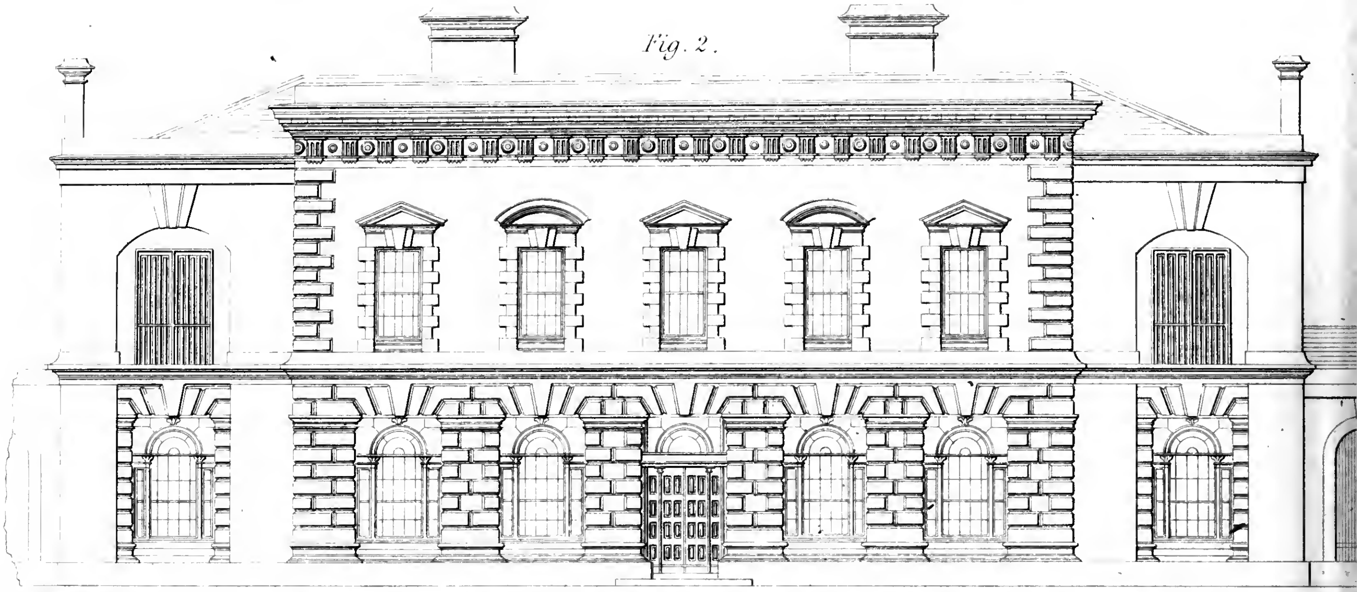


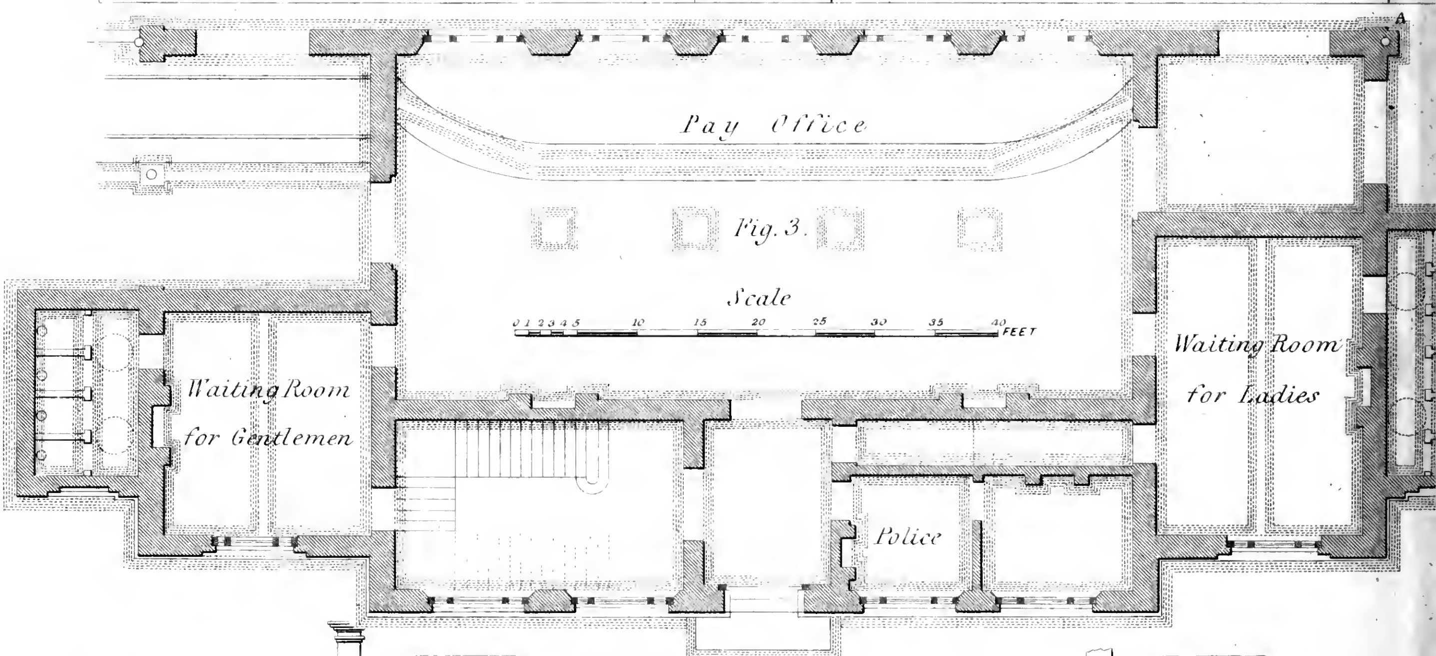
Fig. 5.

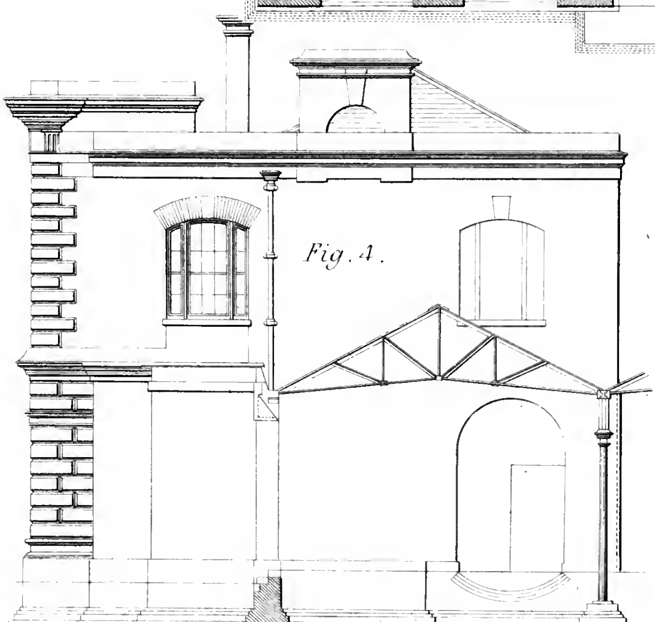
Fig. 4.

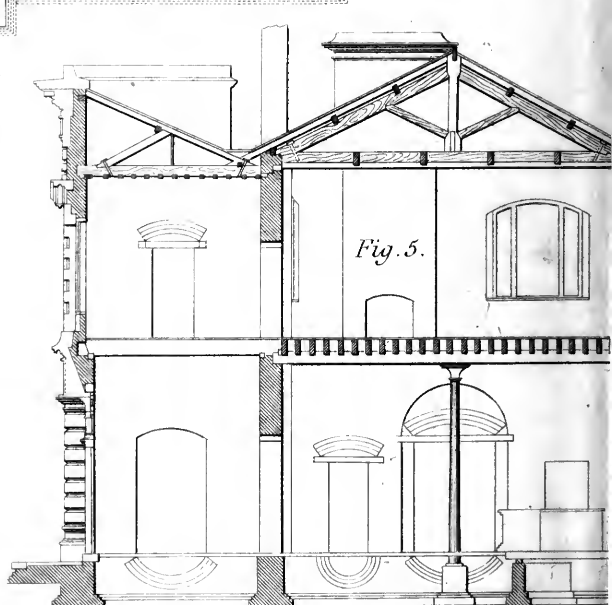


3 4 5 feet



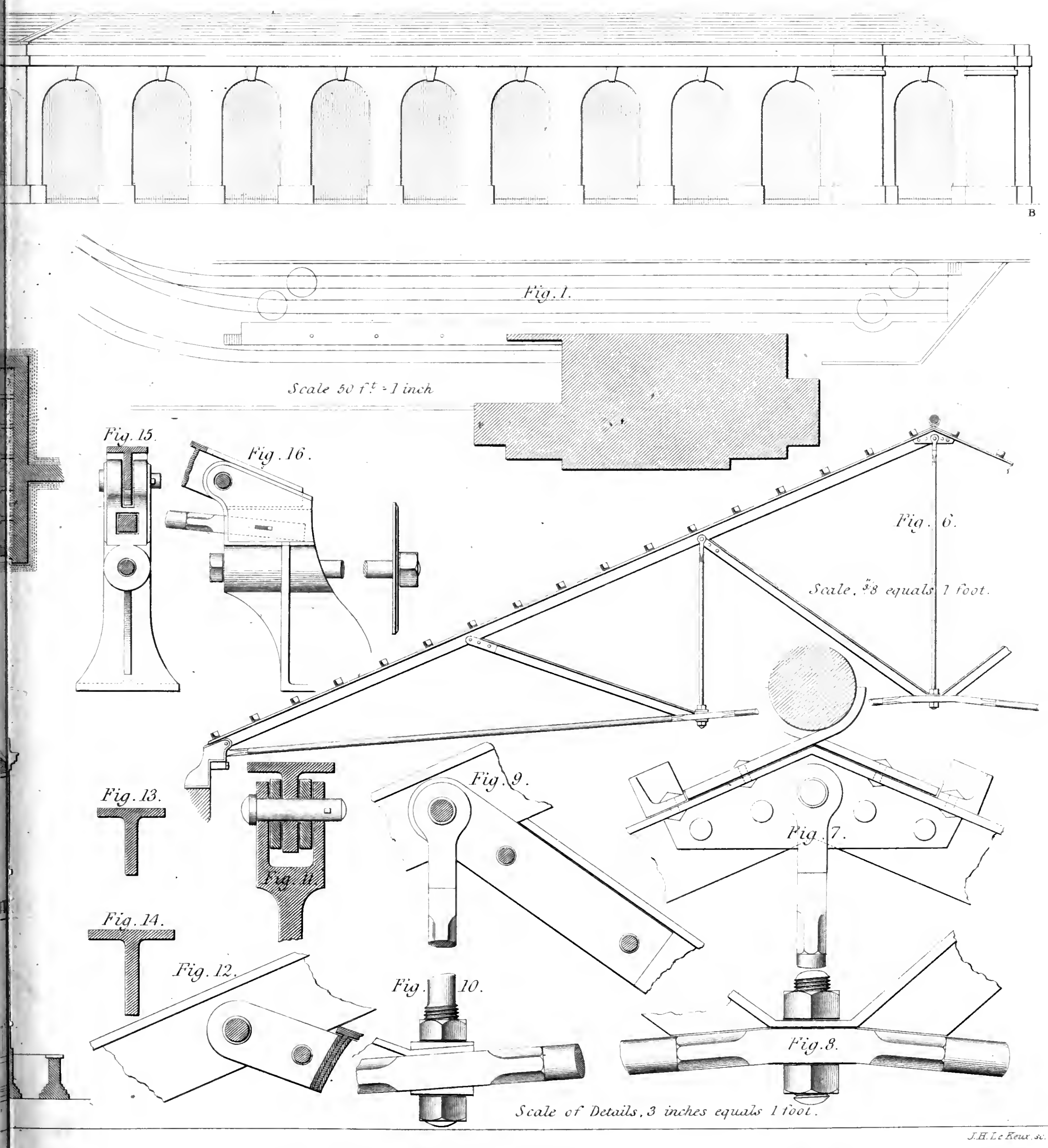






G. D. Dempsey, del.

TERMINAL STATION.



J.H. Le Keux. sc.

TERMINAL STATION

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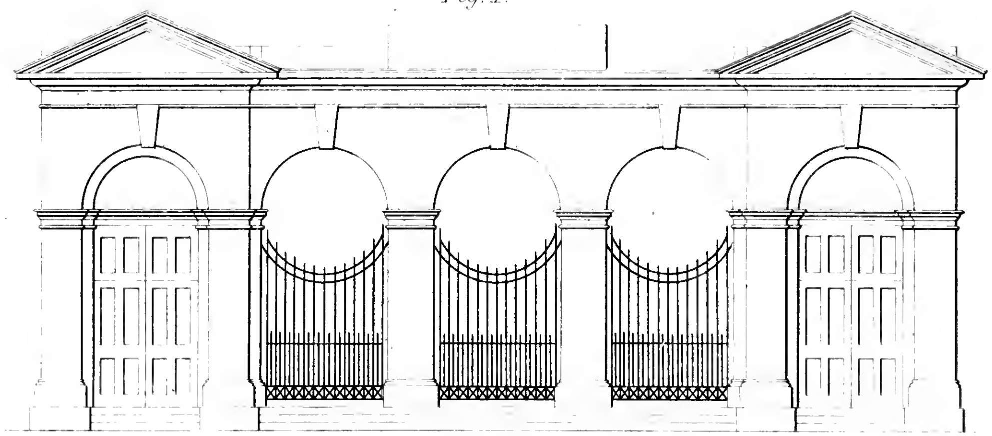
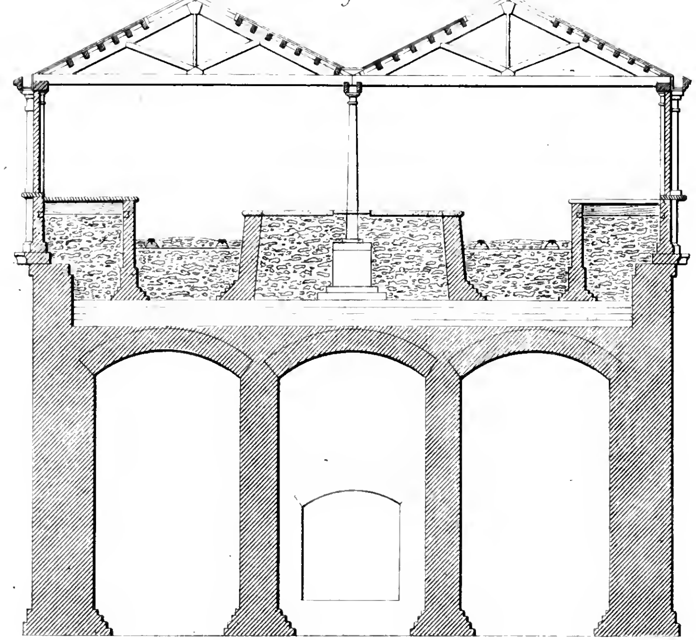


Fig. 4.



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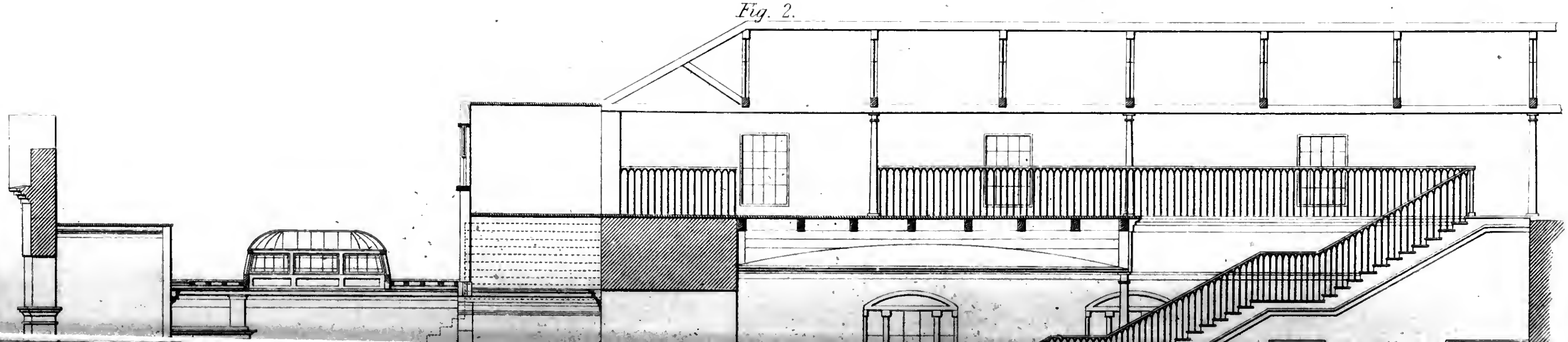

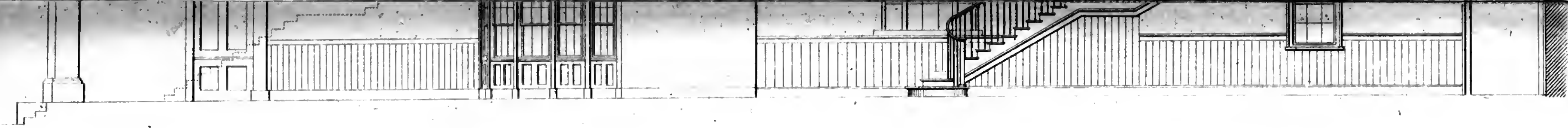

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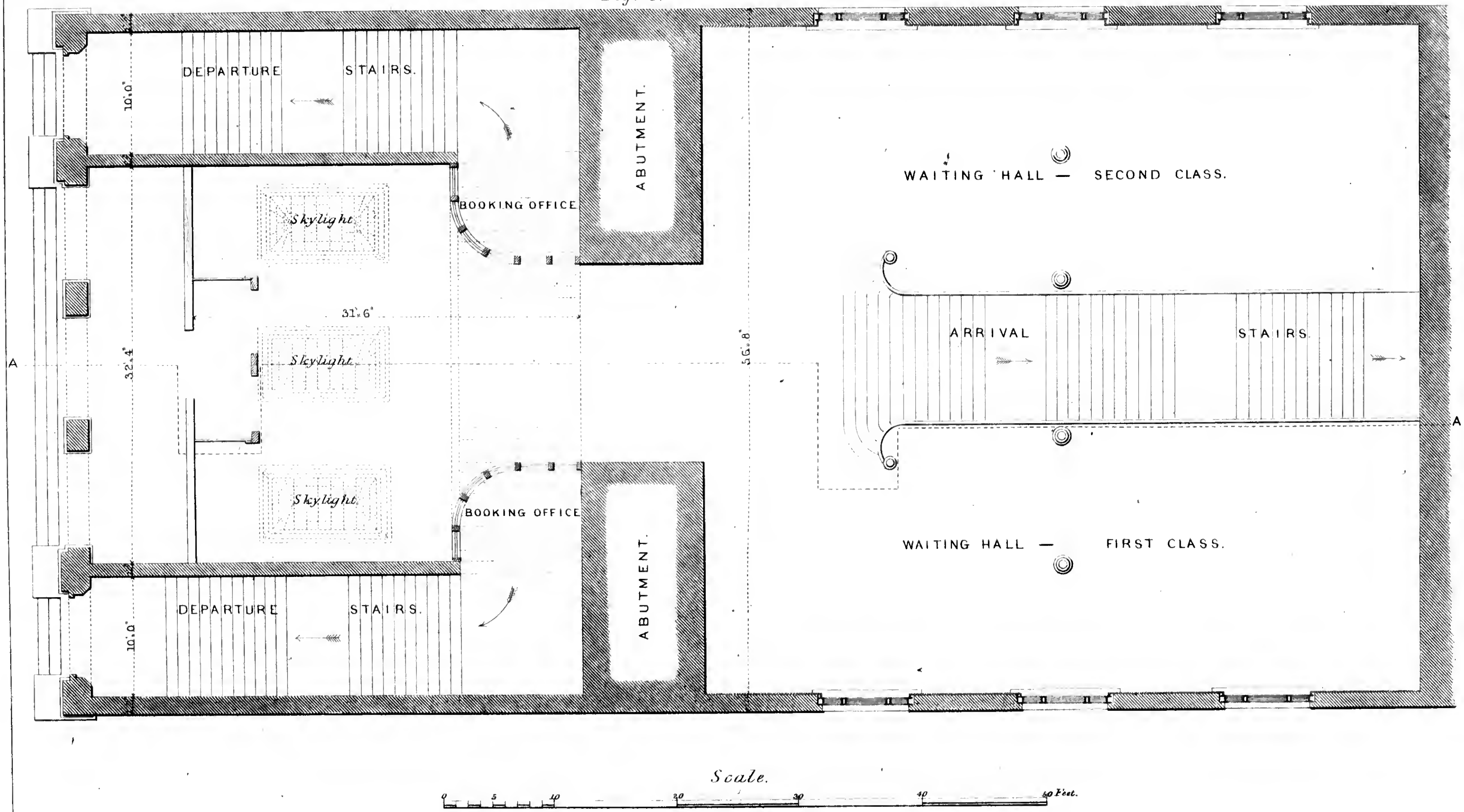
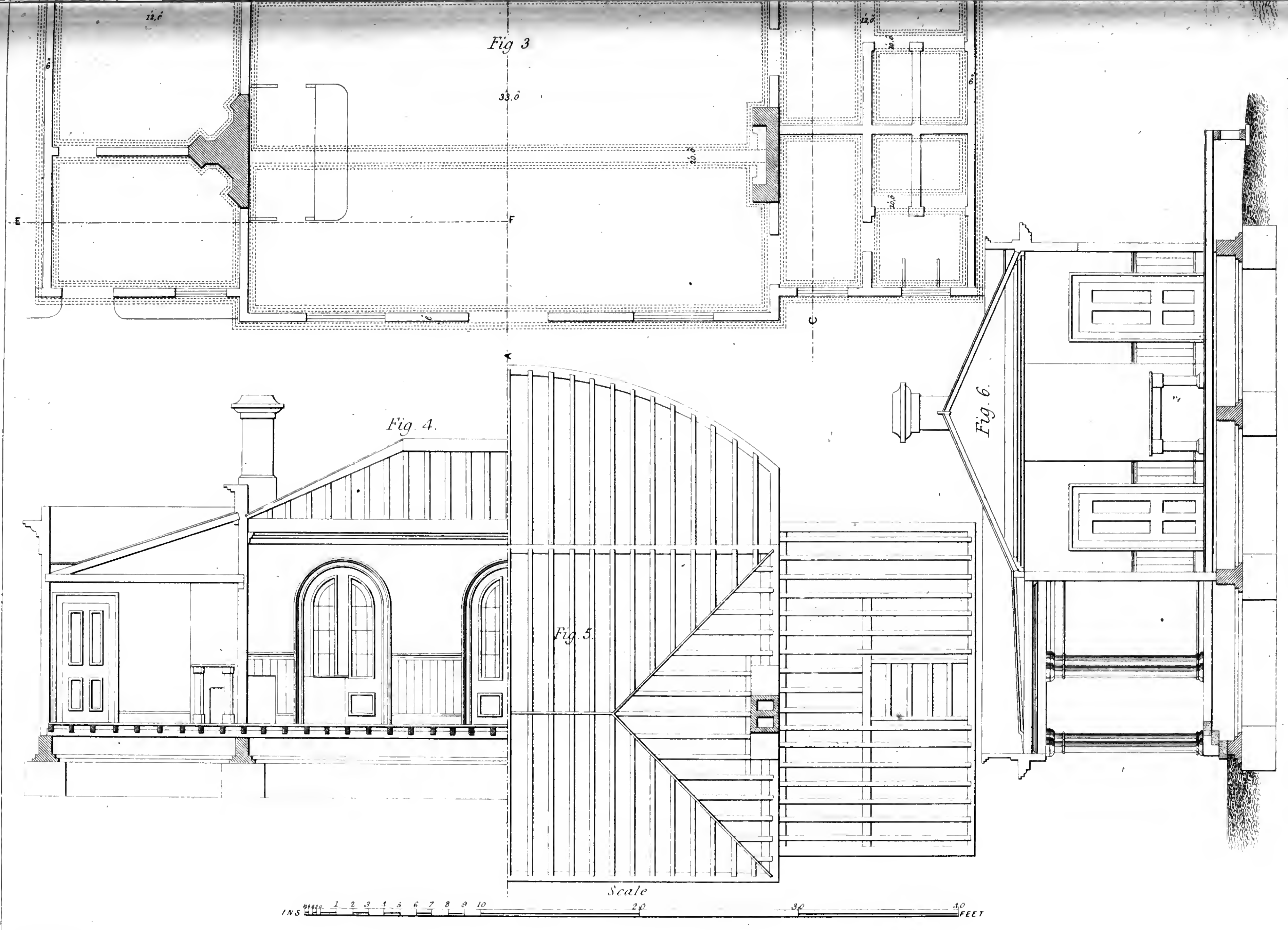


G. D. Dempsey, del.

London, John Weale, 1847.

STATIONS.



G D Dempsey. del

J.H. Le Keux sc

STATIONS.

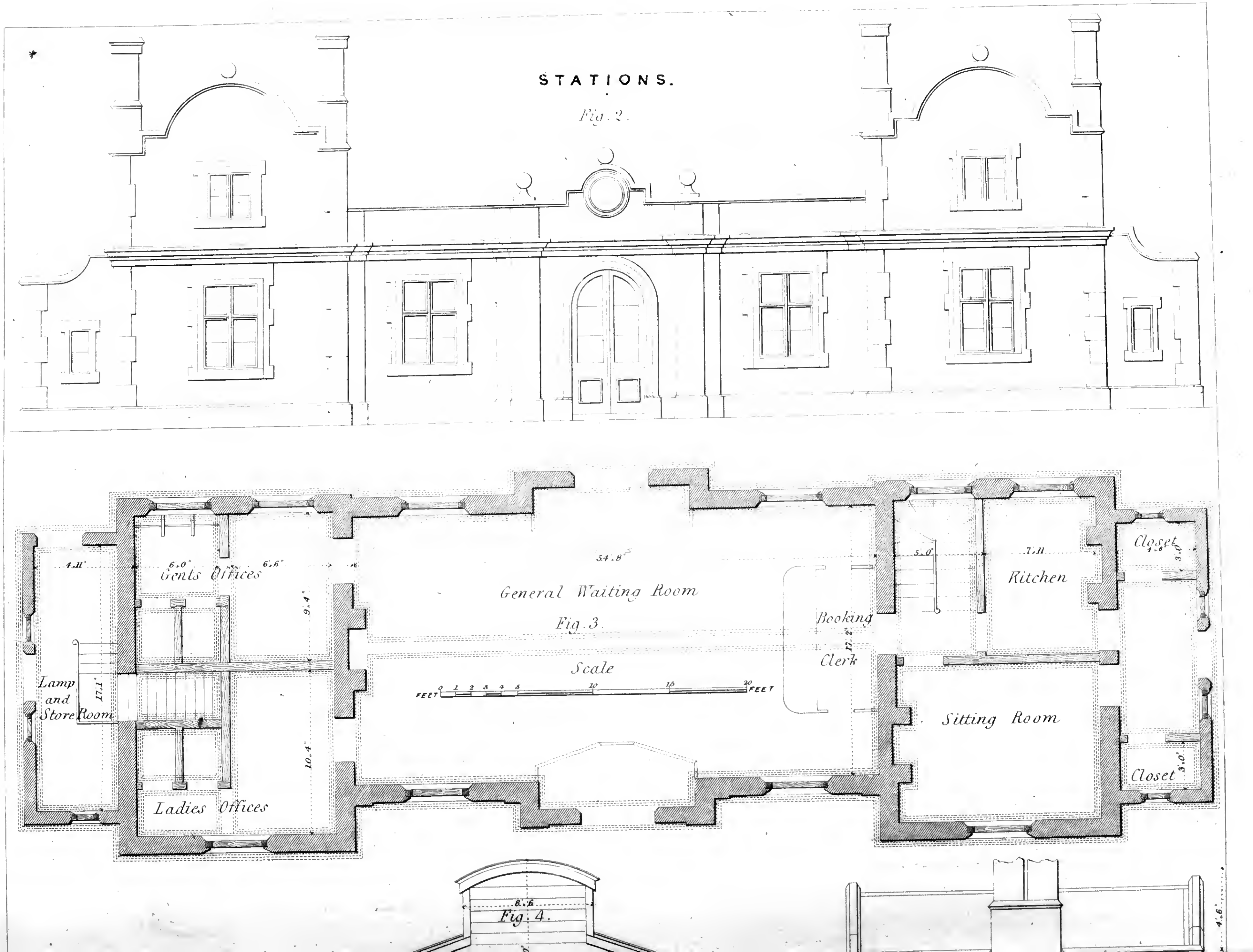
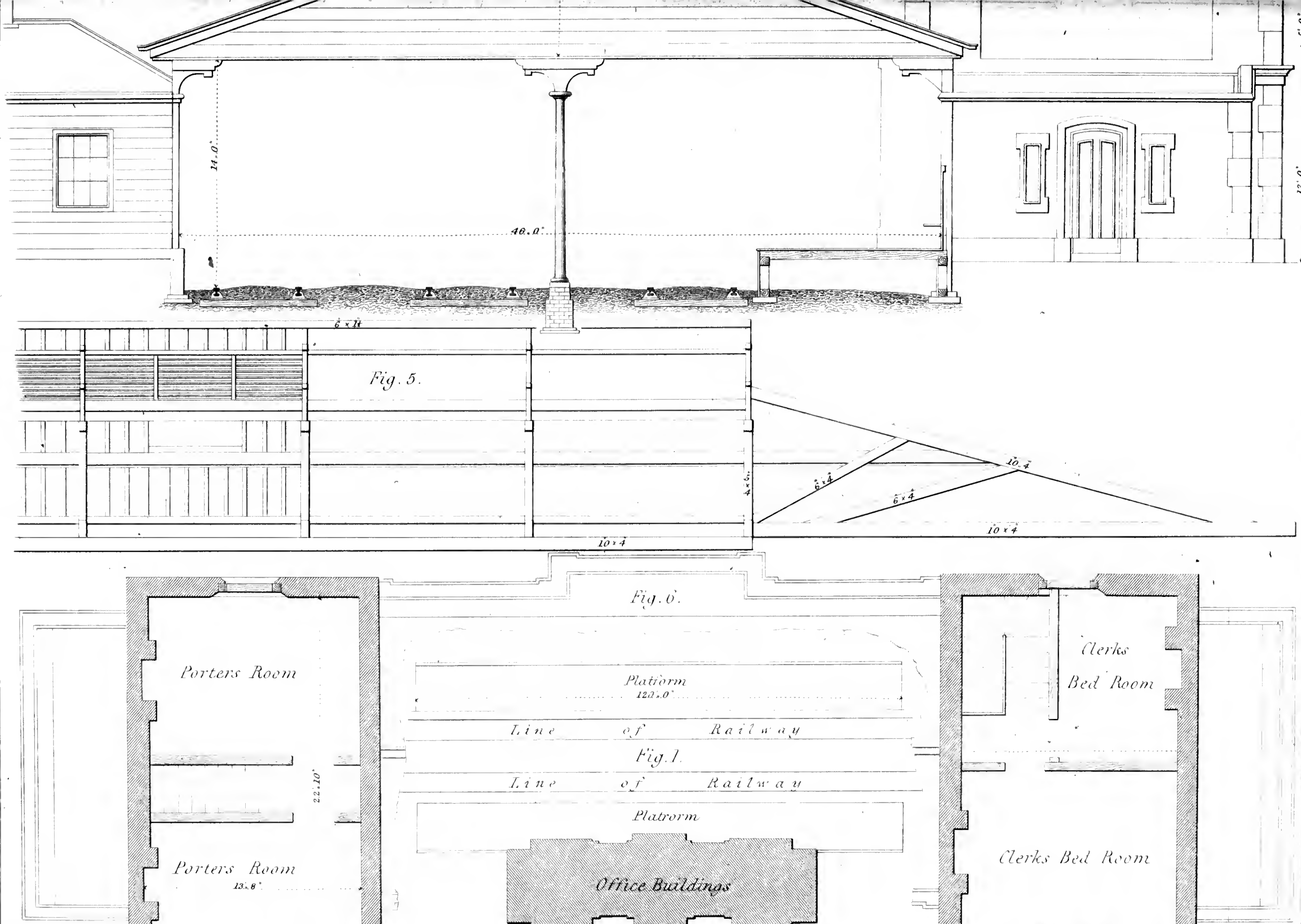


Fig. 2.
54.8
General Waiting Room
Fig. 3.
Scale
FEET 0 1 2 3 4 5 10 15 20 FEET
Booking
Clerk
Kitchen
7.11
5.0
Closet
3.0
Sitting Room
Closet
3.0
Gents Offices
6.0
6.6
9.4
10.4
Ladies Offices
Lamp
and
Store Room
4.11
17.1
8.6
Fig. 4.
4.6



G. D. Dempsey, del.

Scale 32ft 1in

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London; John Weale, 1847

STATIONS.

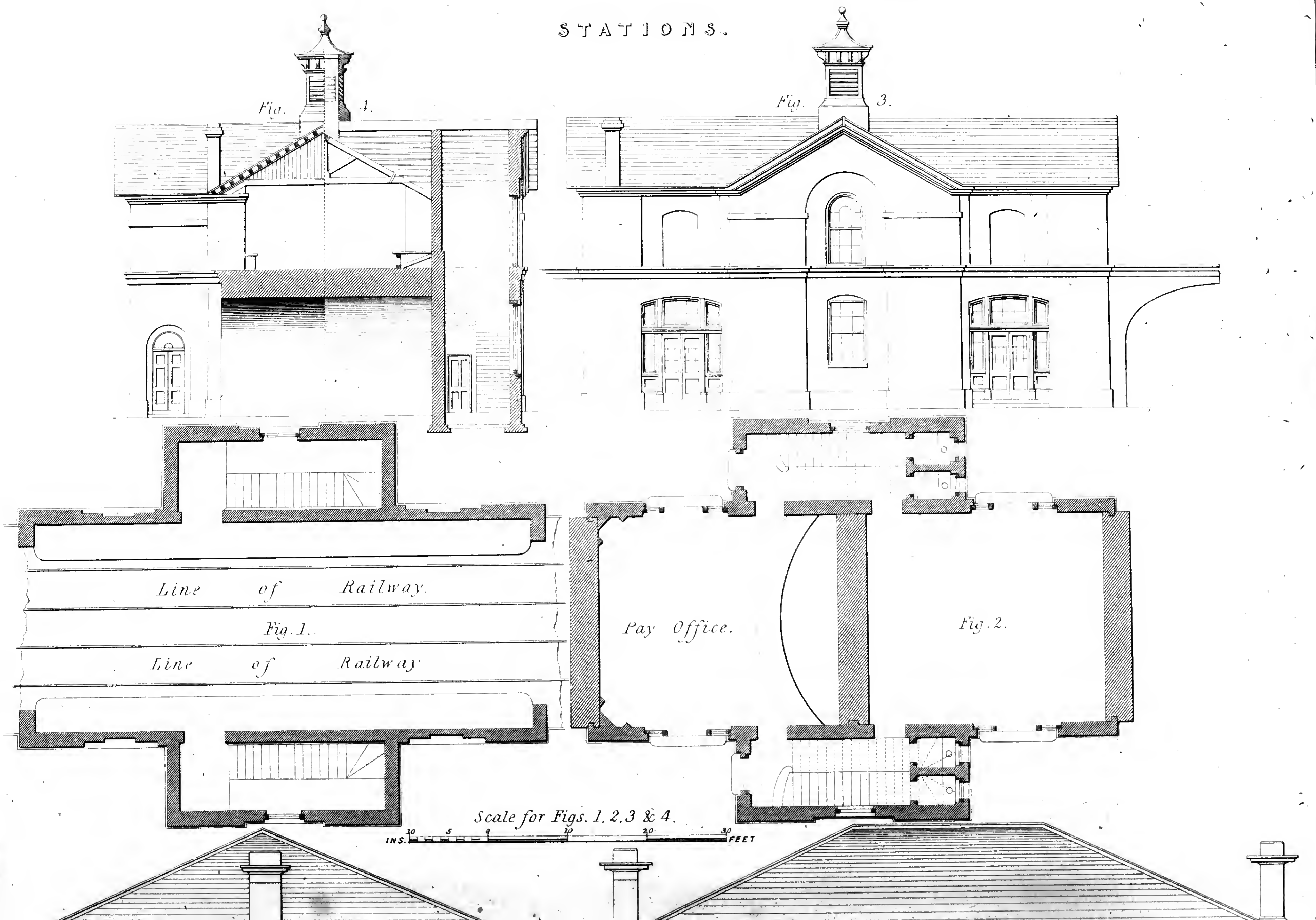
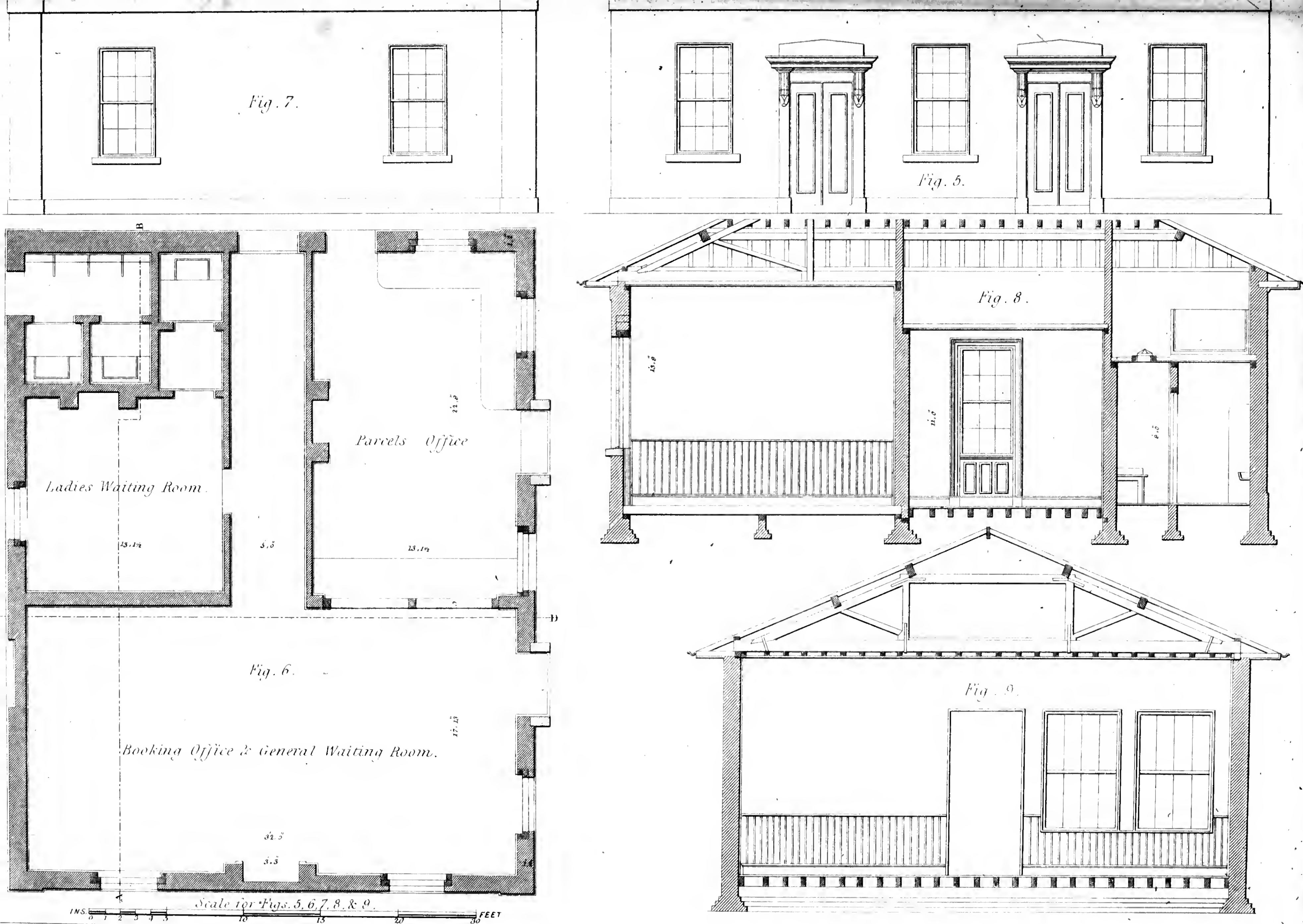


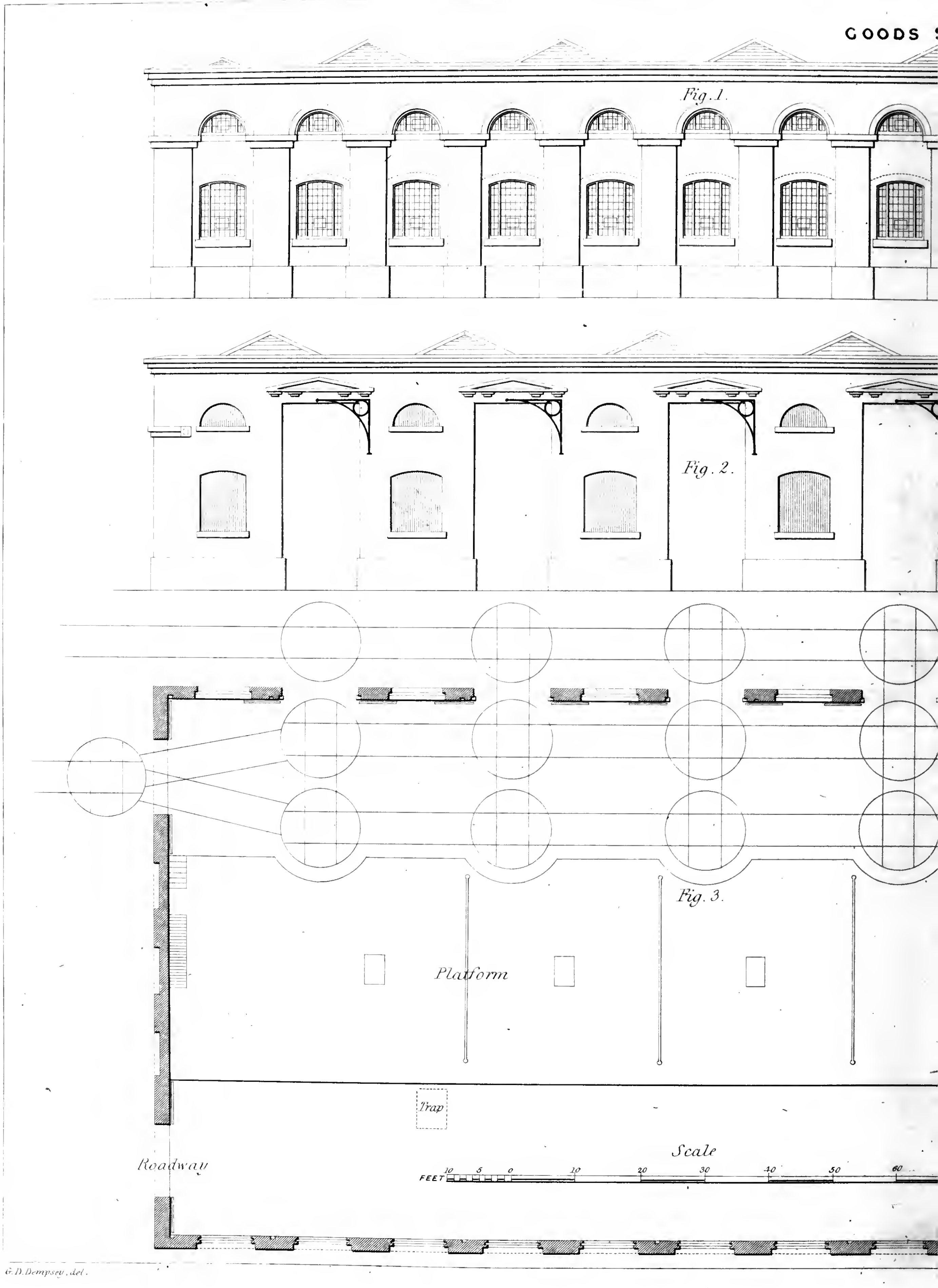
Fig. 4.
Fig. 3.
Line of Railway.
Fig. 1.
Line of Railway
Pay Office.
Fig. 2.
Scale for Figs. 1, 2, 3 & 4.
INS. 10 5 0 10 20 30 FEET



D. Dempsey, del.

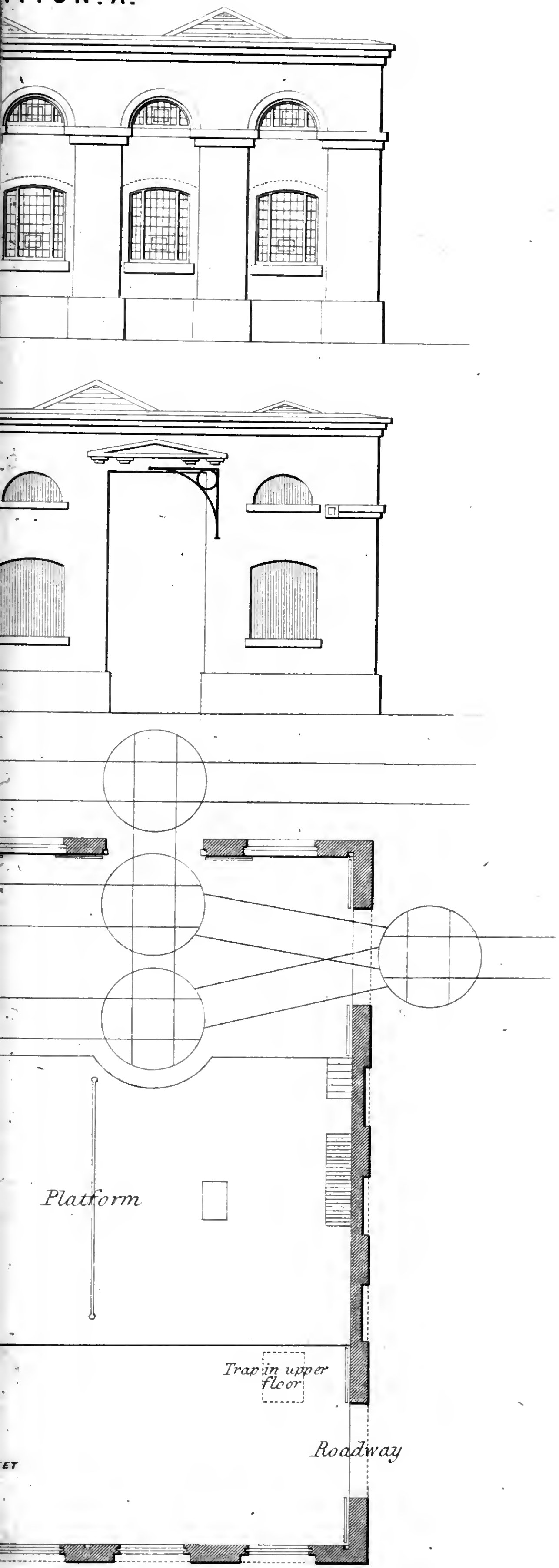
J.H. Le Keux, sc.

London, John Weale, 1847



G. D. Dempsey, del.

ATION. A.



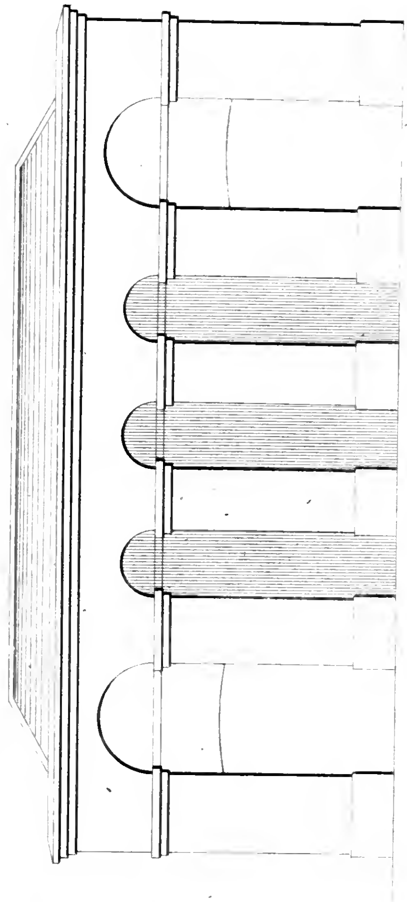


Fig. 5.

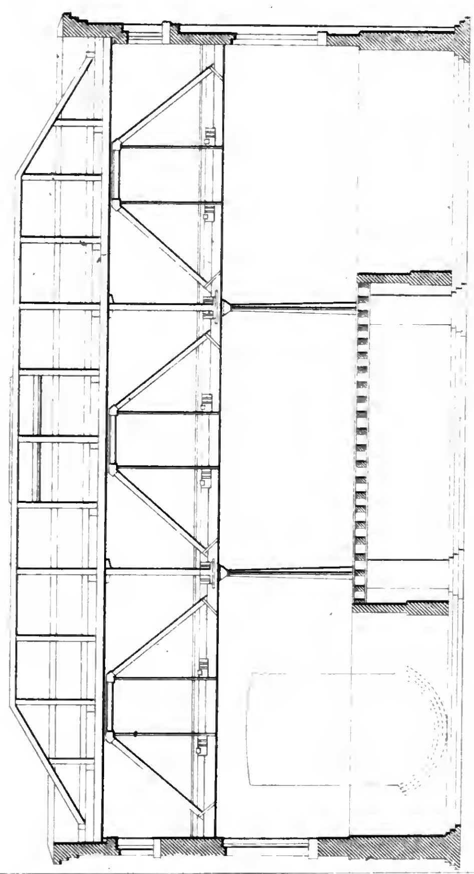


Fig. 4.

J. H. Le K ur...

ENCINE HOUSE.

Fig. 1.

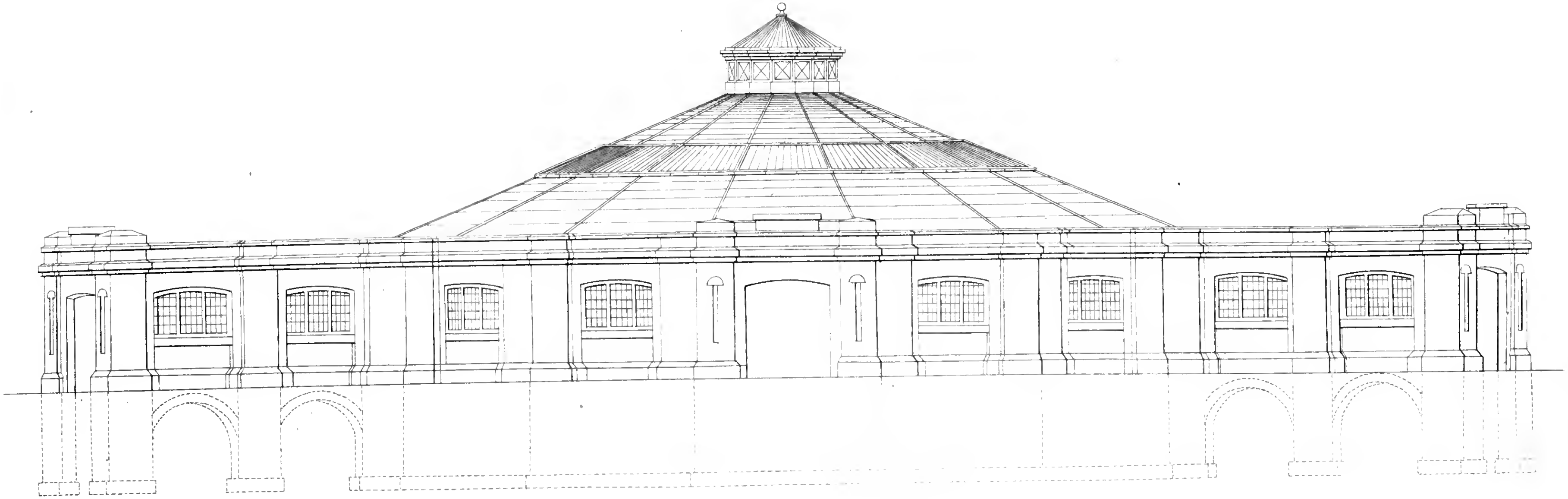
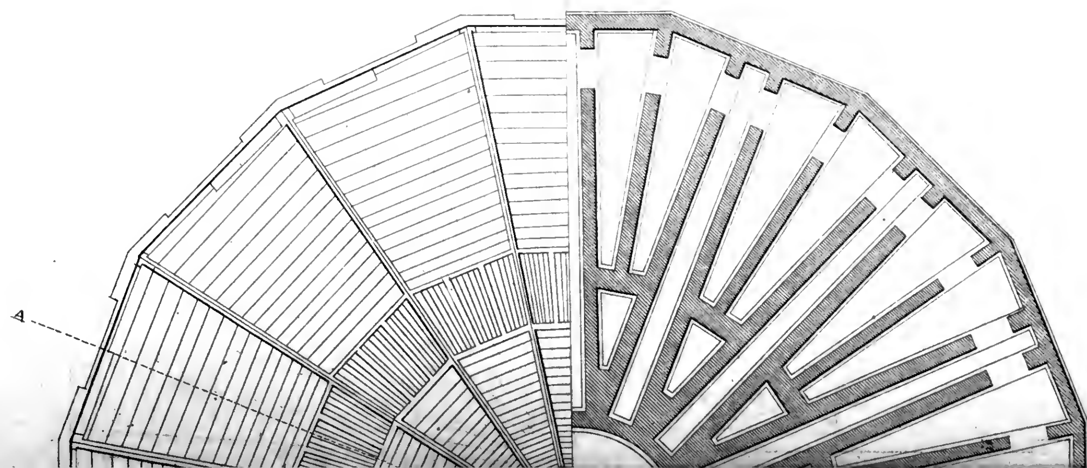


Fig. 2.



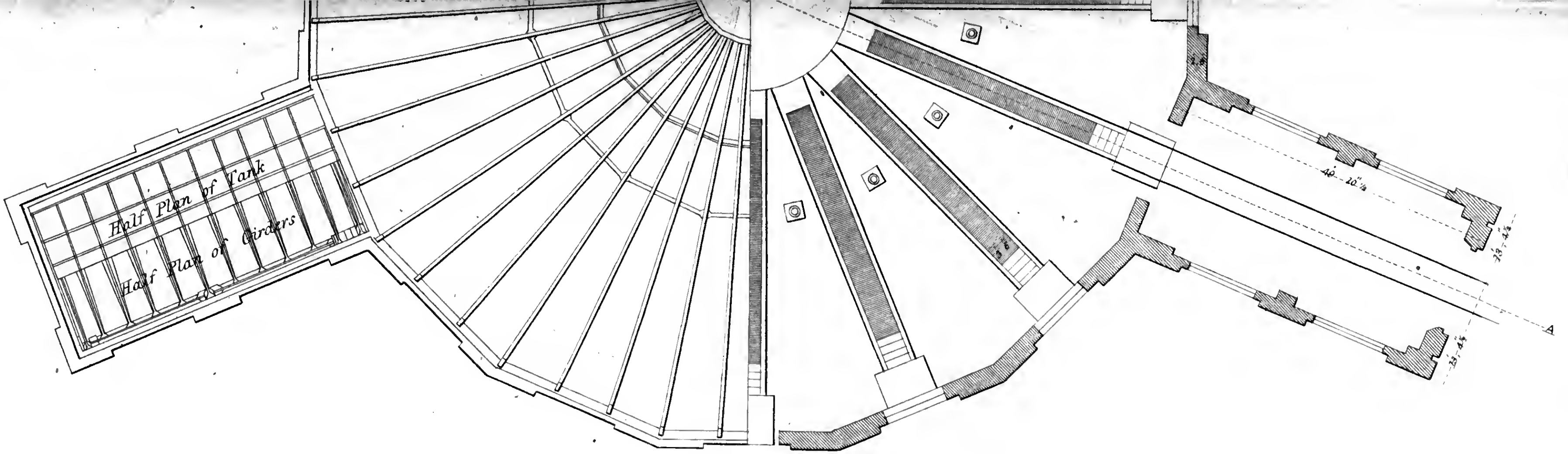
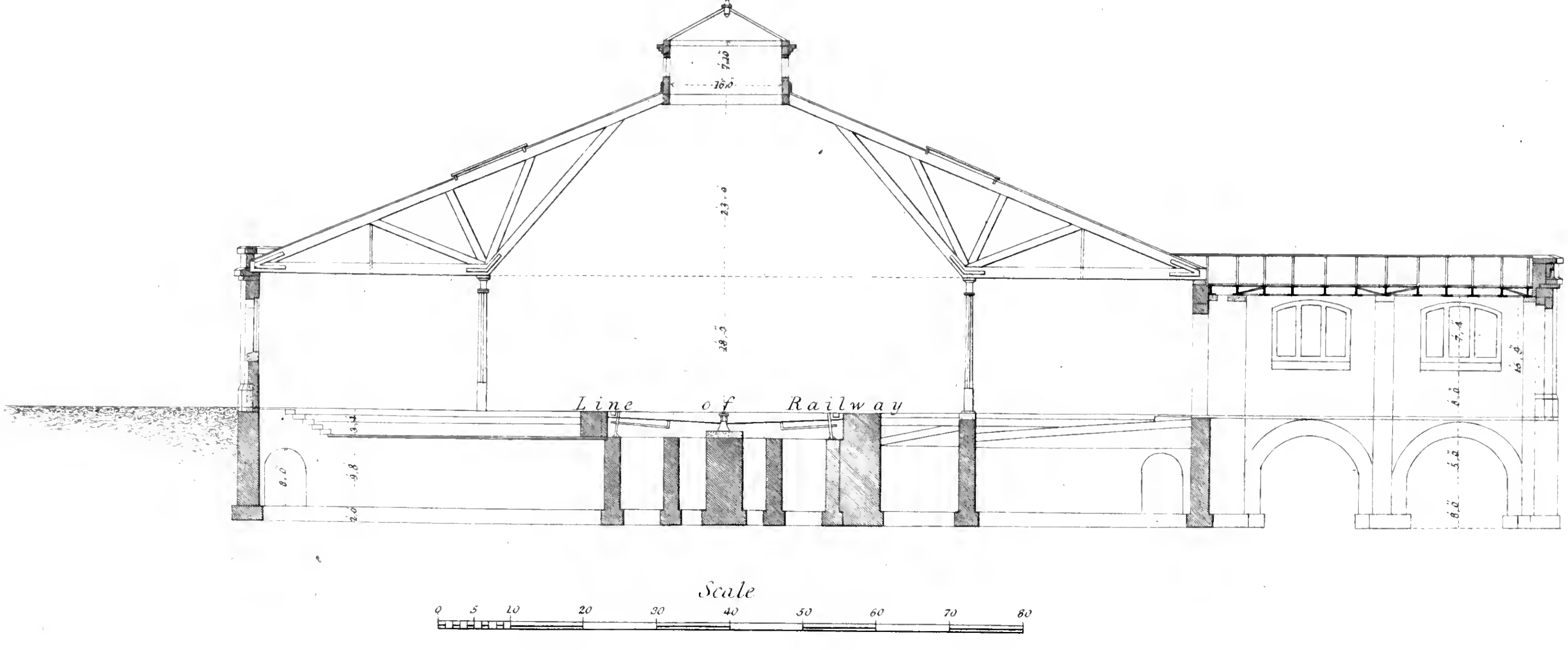
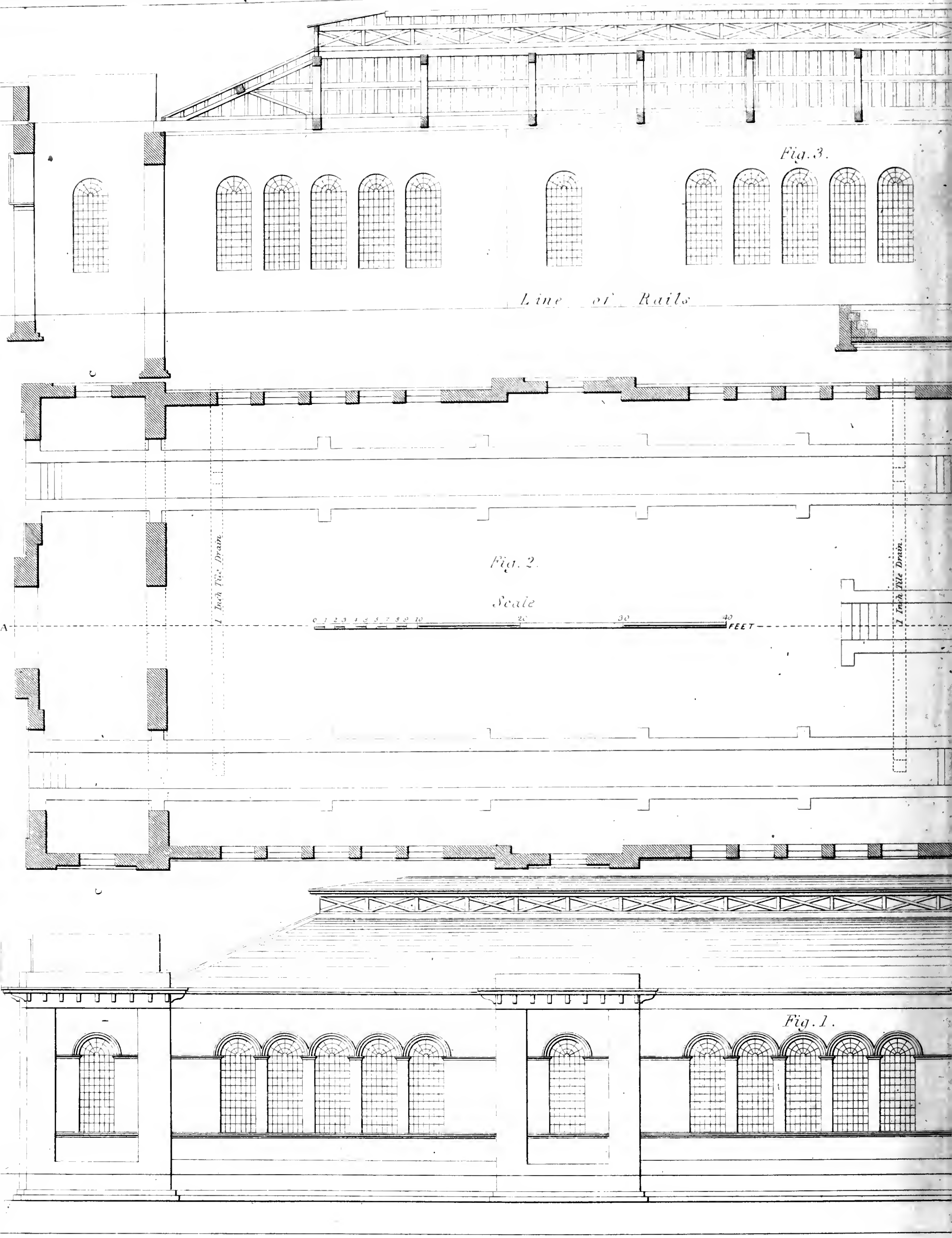


Fig. 3.



G. D. Dempsey, del.

J. Hawksworth, sc.



D. Dempsey del.

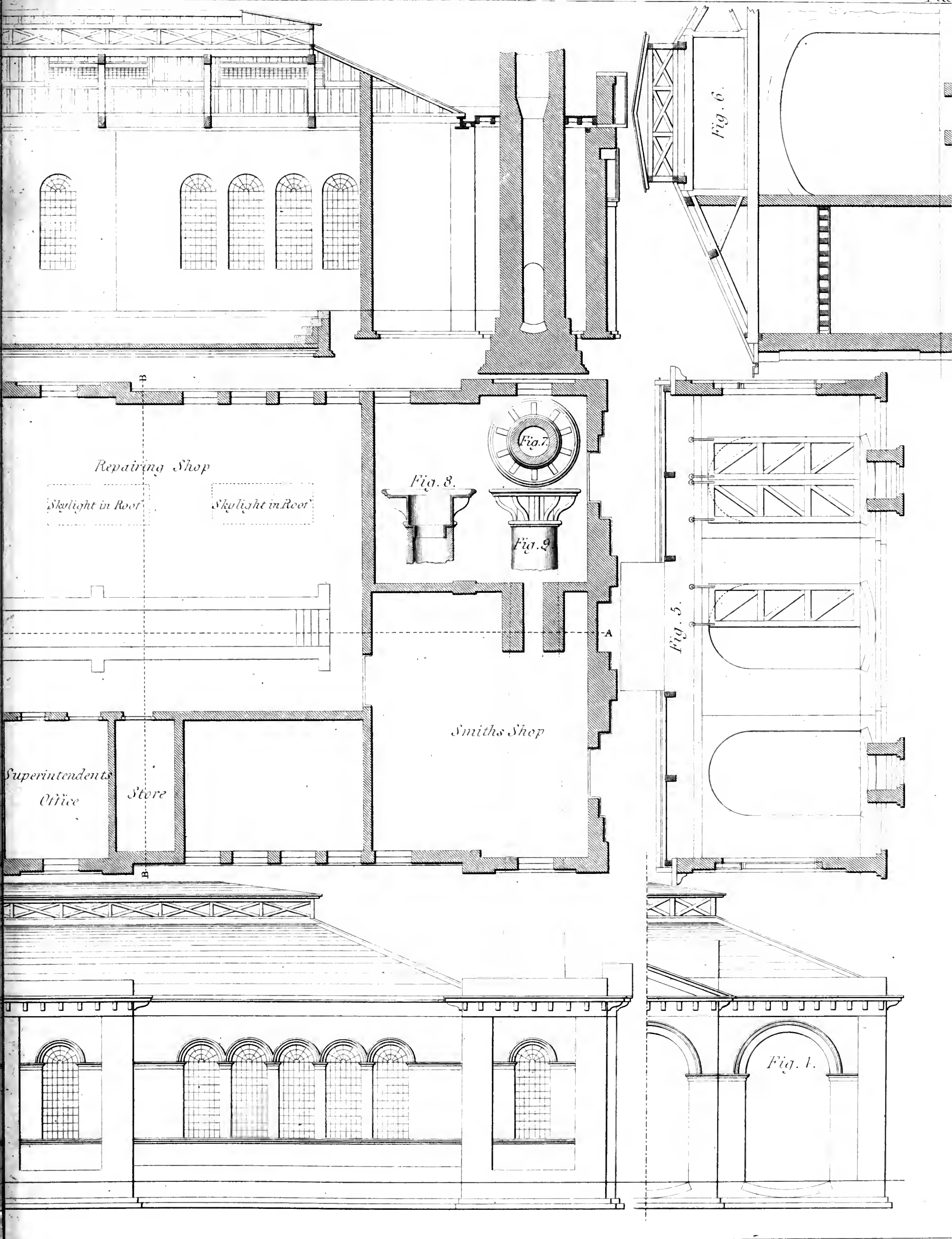
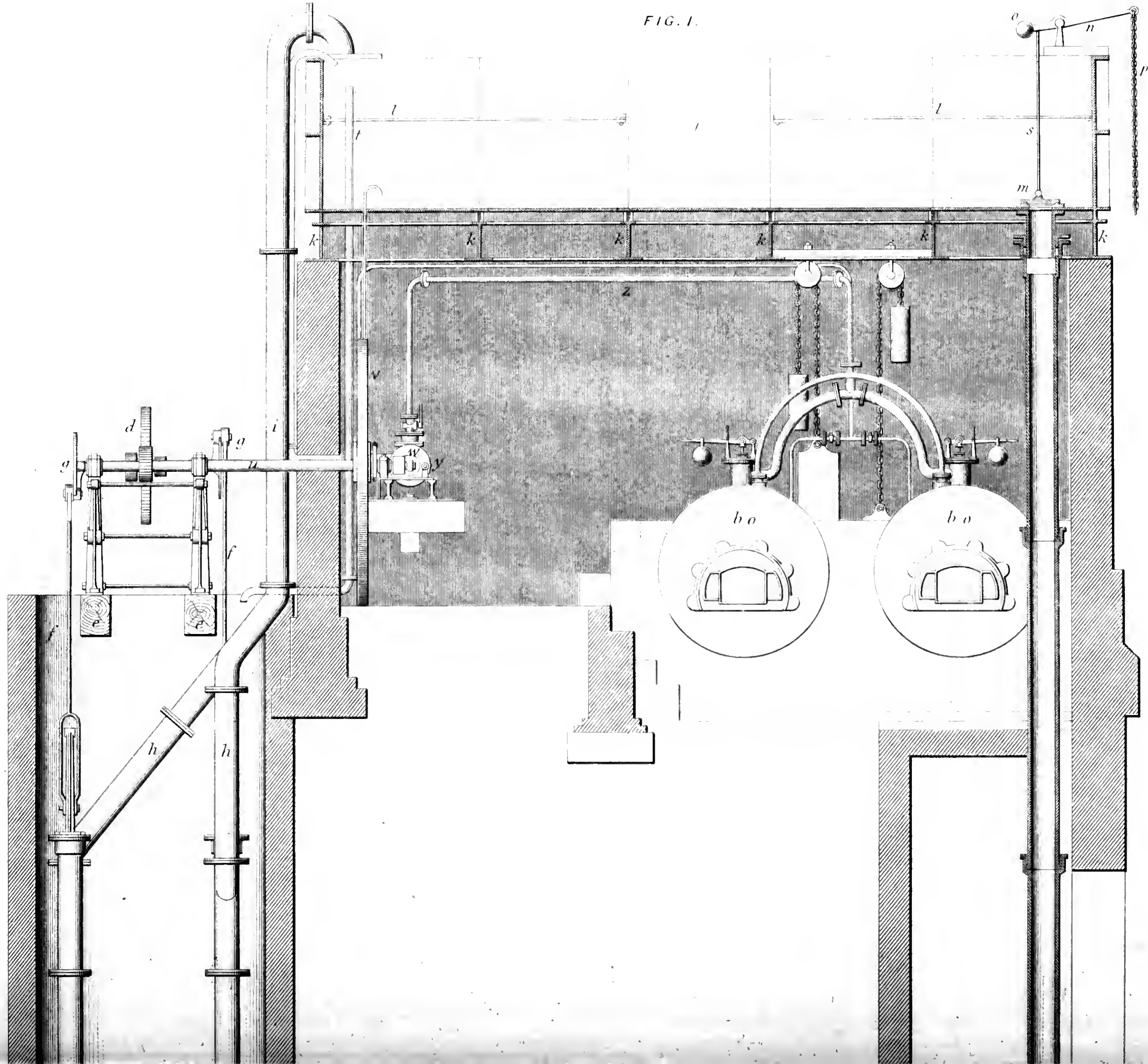


Fig. 6.
Repairing Shop
Skylight in Roof
Skylight in Roof
Fig. 7.
Fig. 8.
Fig. 9.
A
B
Fig. 5.
Smiths Shop
Superintendents Office
Store
Fig. 1.

WATERING APPARATUS. A.

FIG. I.



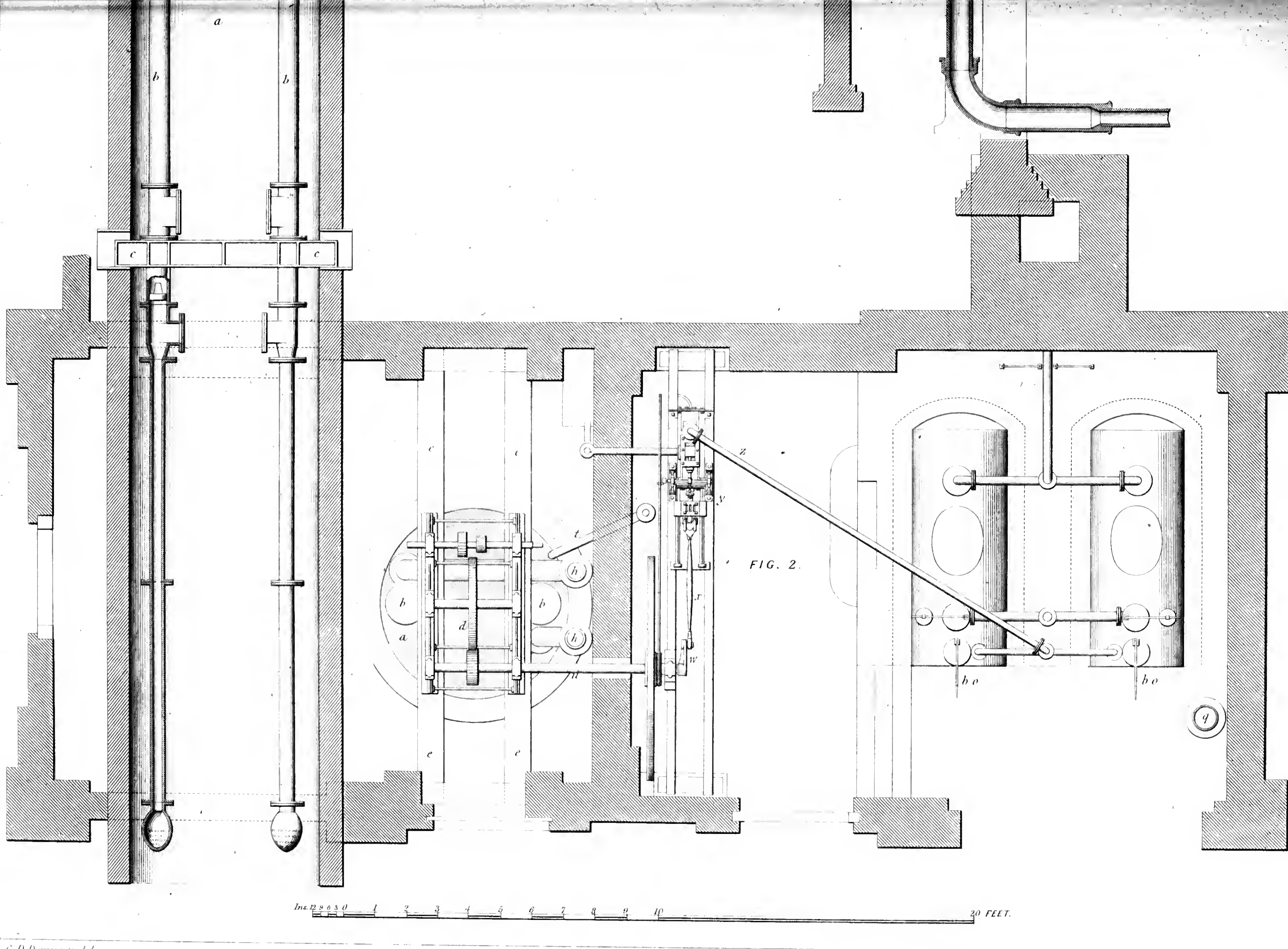
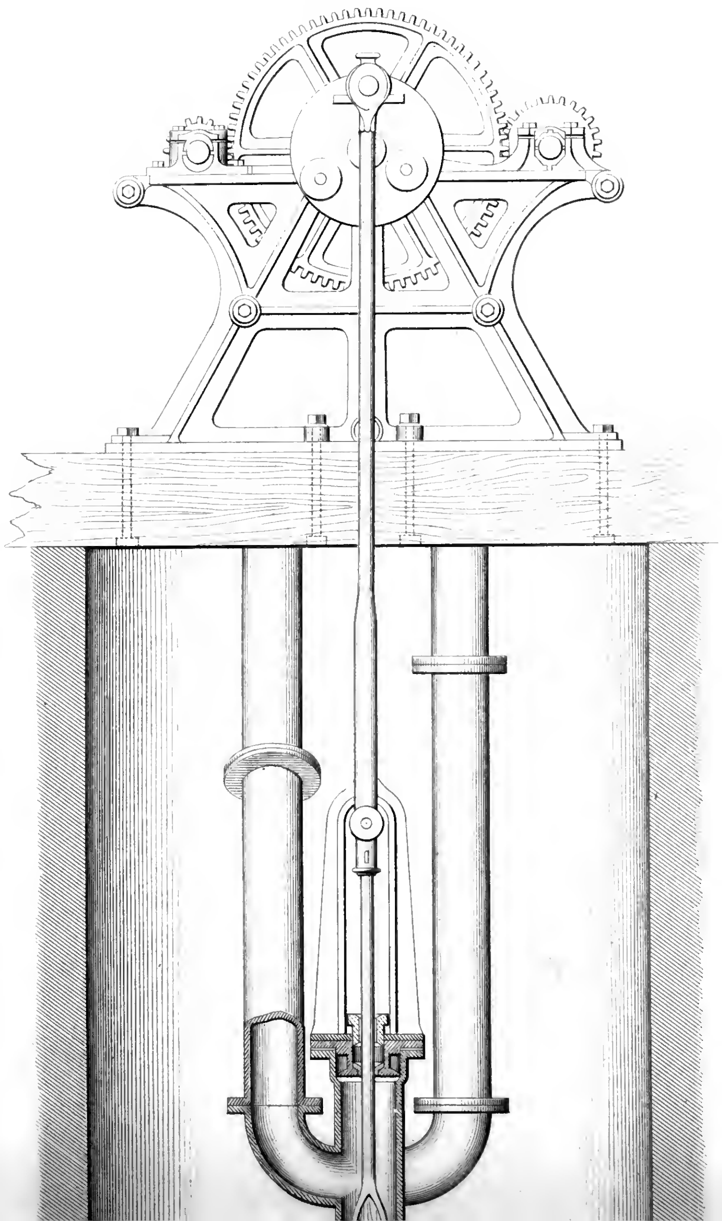


FIG. 2.

G. D Dempsey del

WATERING APPARATUS B.

Fig. 1.



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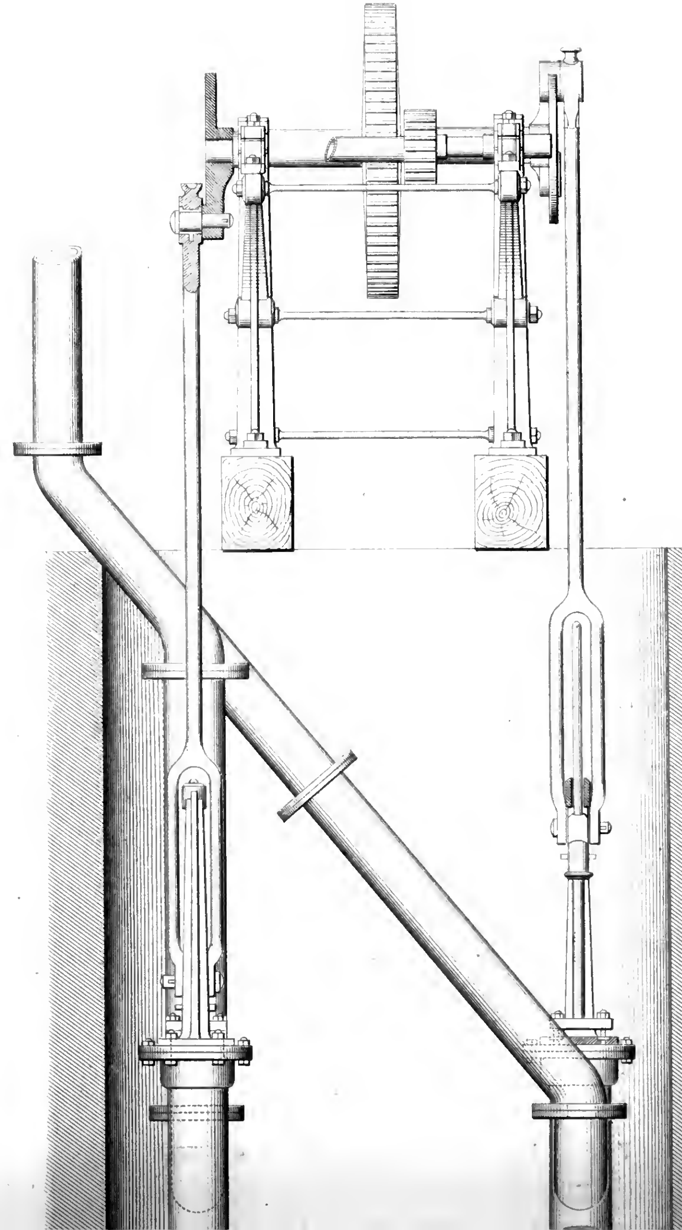
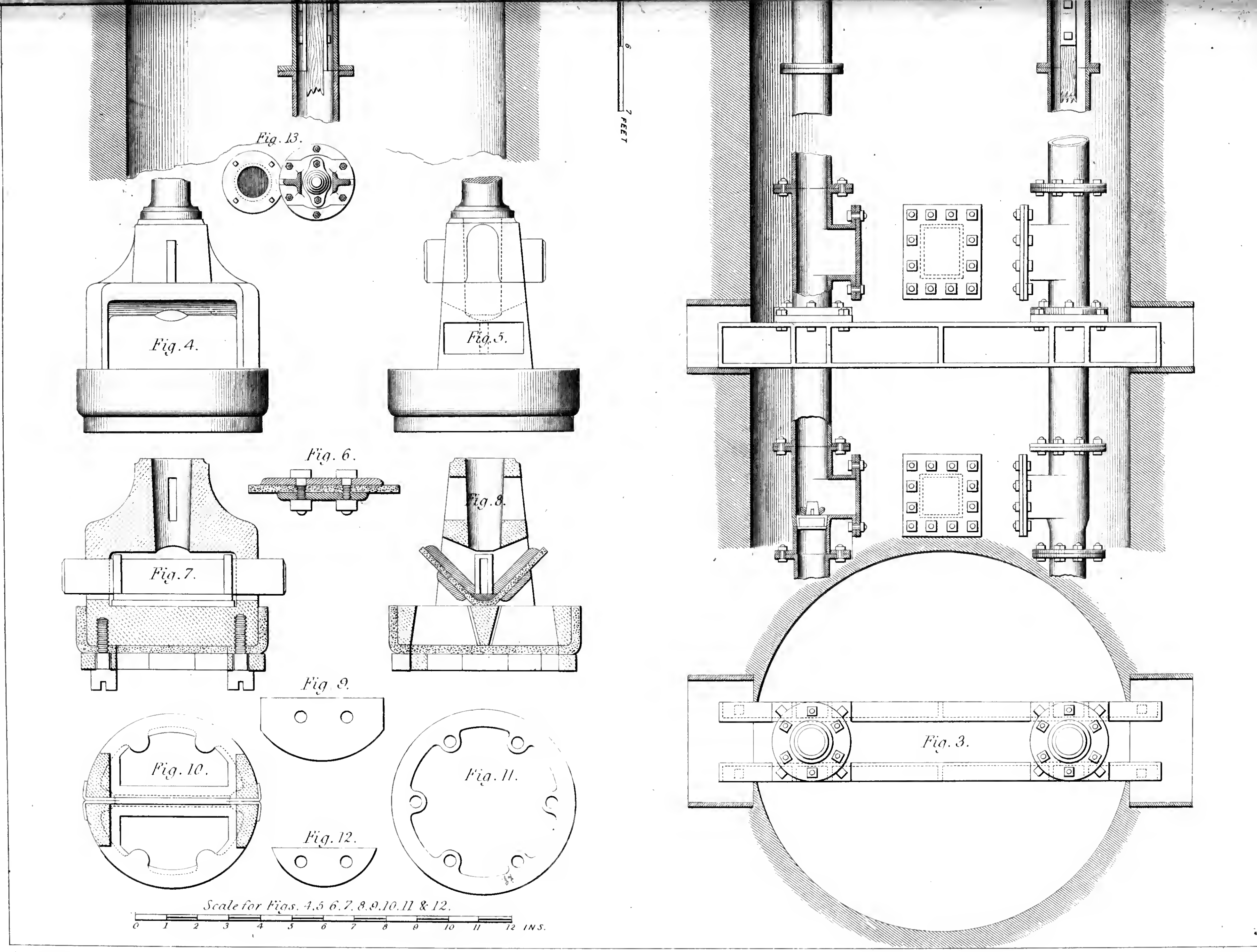


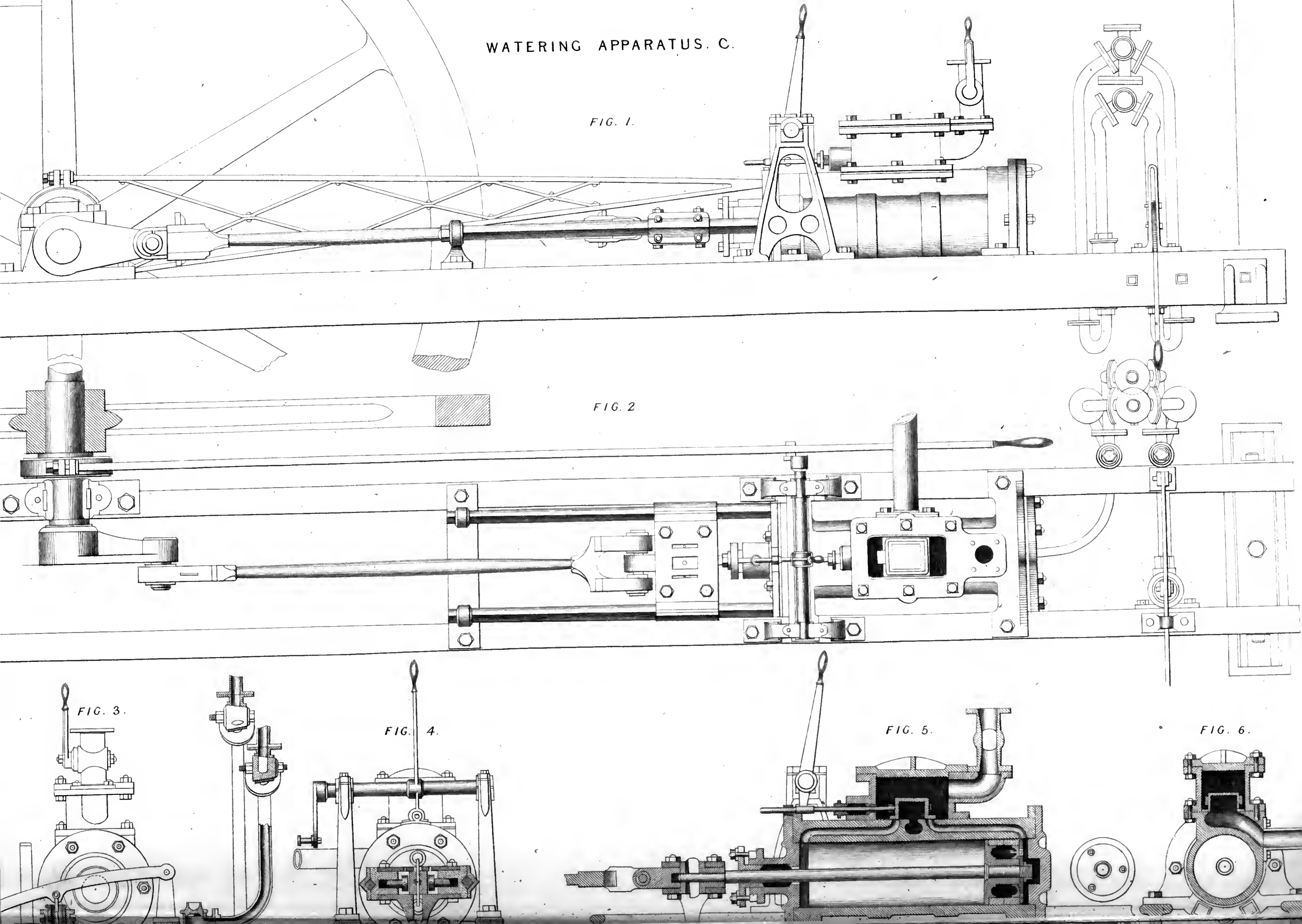
Scale for Figs 1.2.3 & 13.

INS. 12 9 6 3 0 1 2 3 4



6
7 FEET
Fig. 13.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.
Fig. 8.
Fig. 9.
Fig. 10.
Fig. 11.
Fig. 12.
Fig. 3.
Scale for Figs. 4.5 6.7. 8.9.10.11 & 12.
0 1 2 3 4 5 6 7 8 9 10 11 12 INS.

WATERING APPARATUS. C.



Scale for Figs. 1 to 6 inclusive.

Ins. 12 9 6 3 0 1 2 3 FEET

FIG. 7.

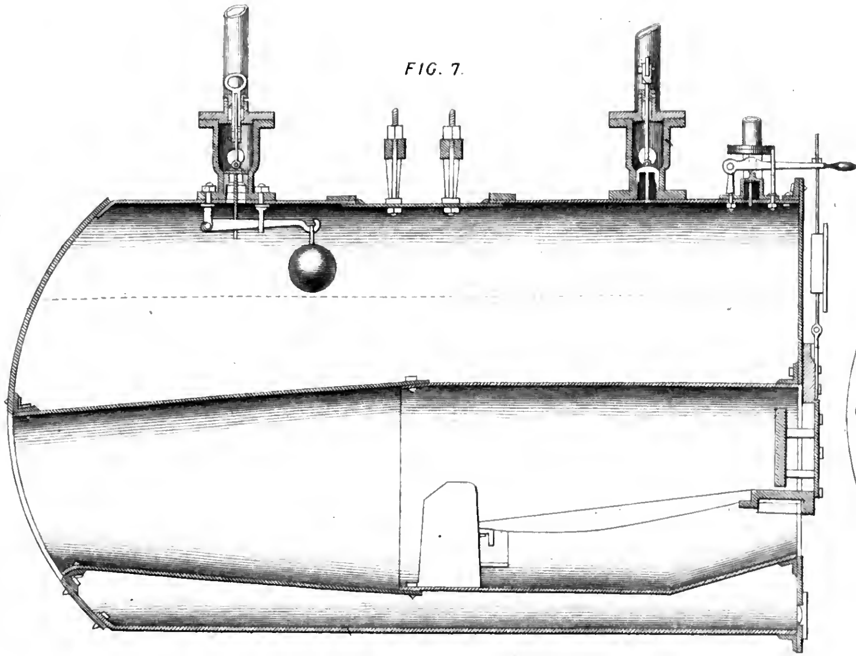


FIG. 8.

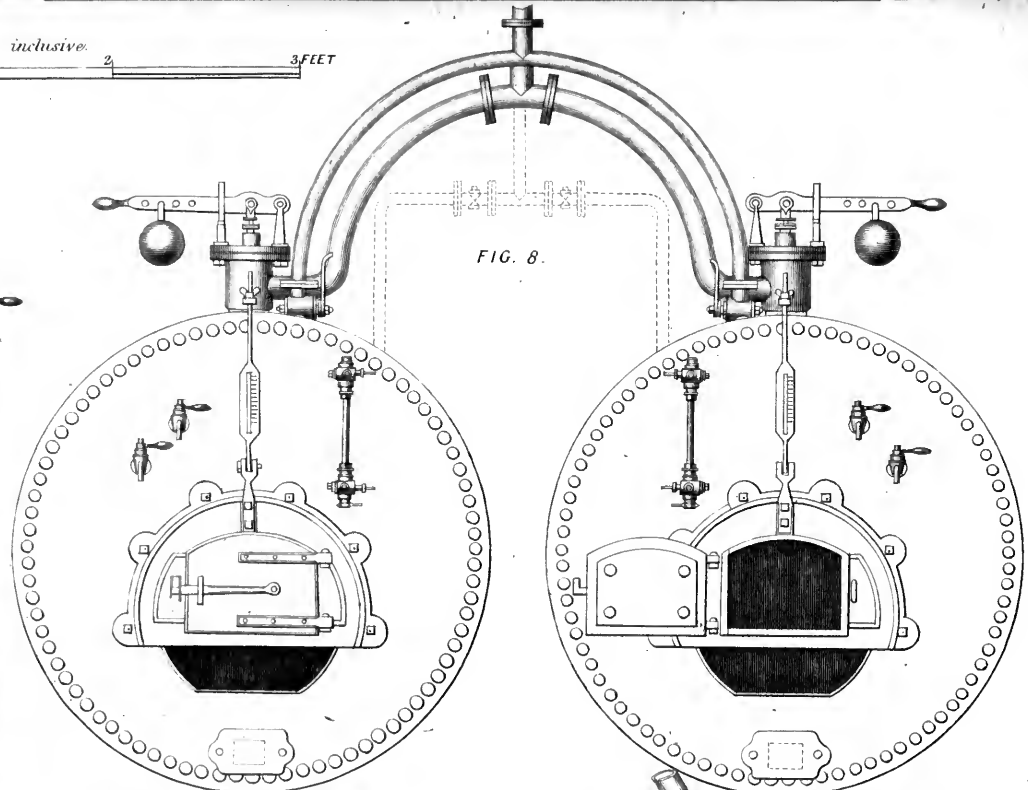


FIG. 9.

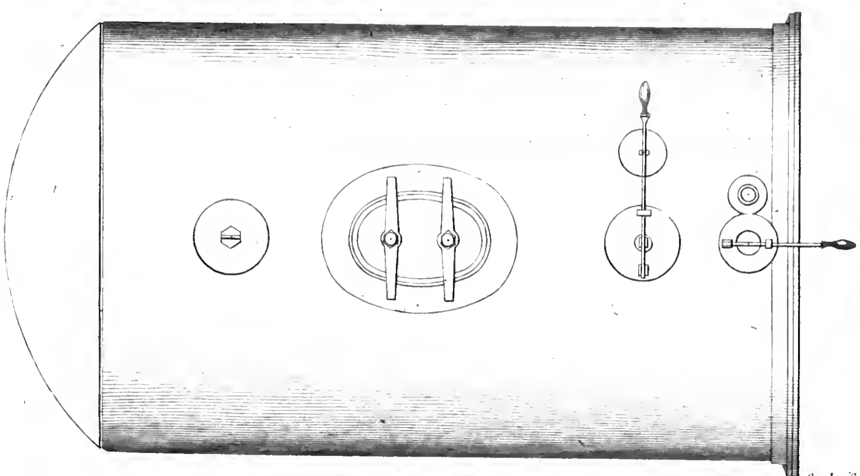
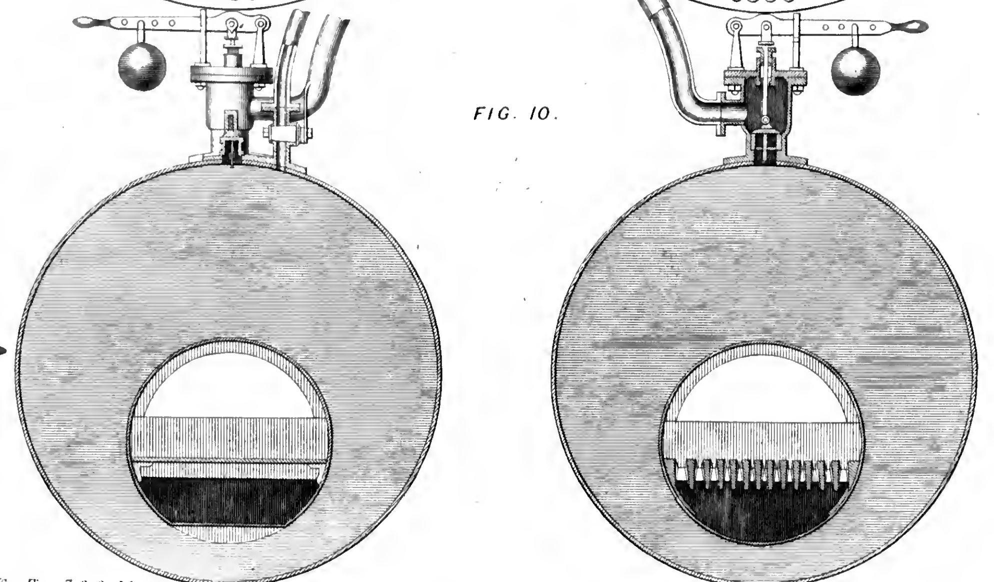


FIG. 10.



Scale for Figs. 7. 8. 9. 10.

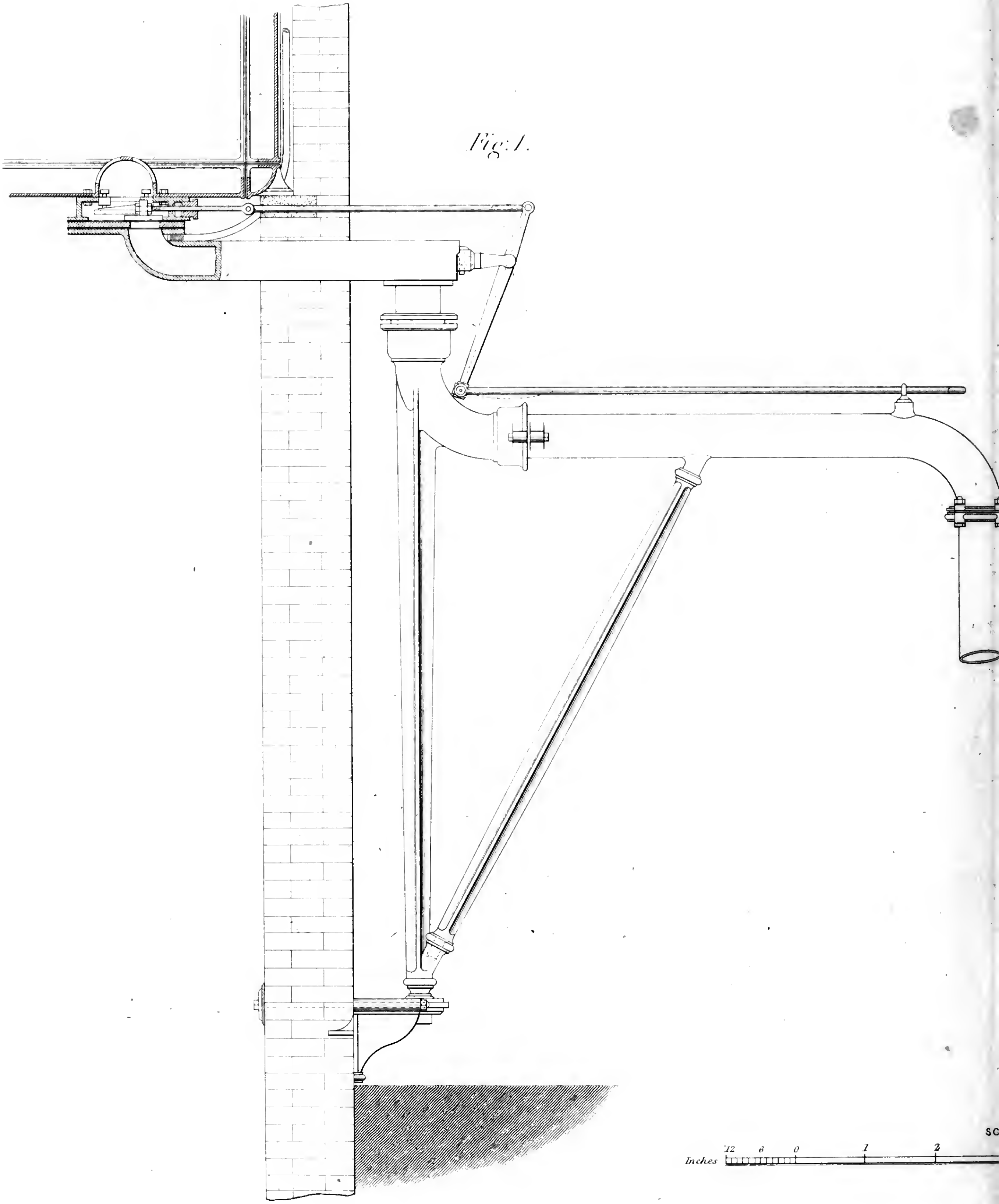
Ins. 12 9 6 3 0 1 2 3 4 5 6 7 FEET

G. D. Dempsey del.

London. John Weale. 1847

WATERING A

Fig: 1.



SC

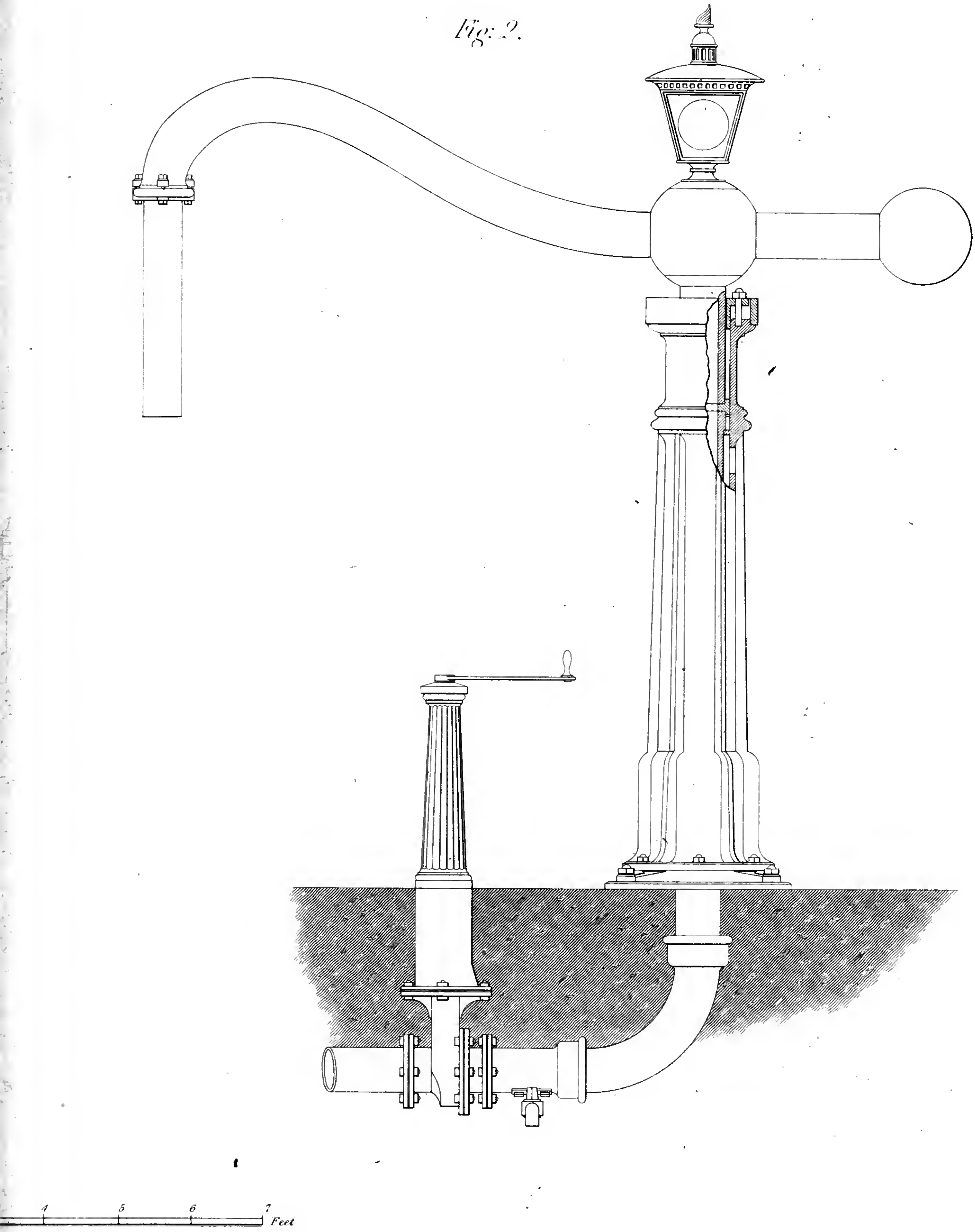
Inches 12 6 0 1 2

G.D. Dempsey del.

Published by John Weale

PPARATUS . D.

Fig: 2.

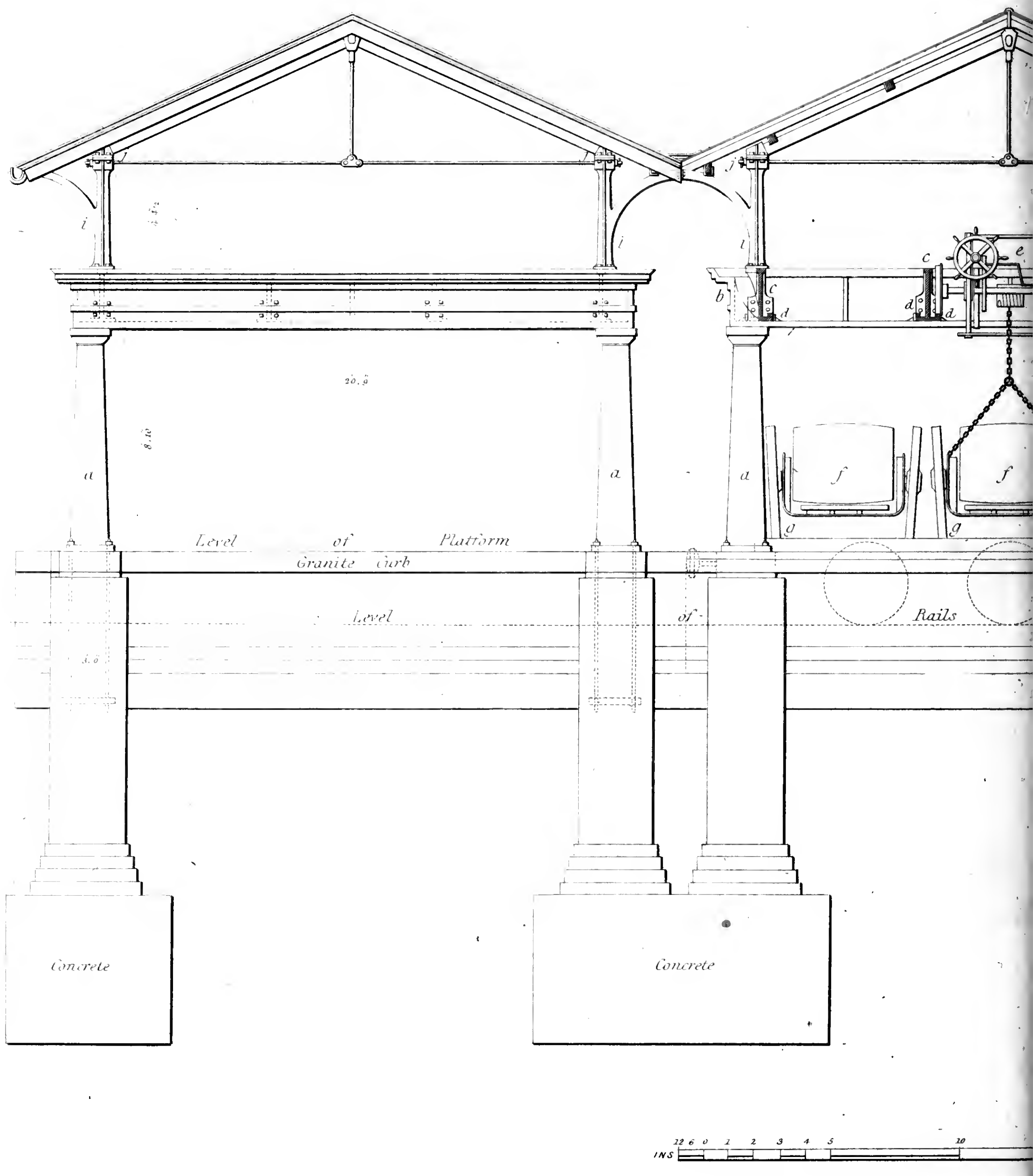


B.R.Davies sculp.

tural Library 59 High Holborn 1847.

Fig. 1.

Fig. 2.



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London; J

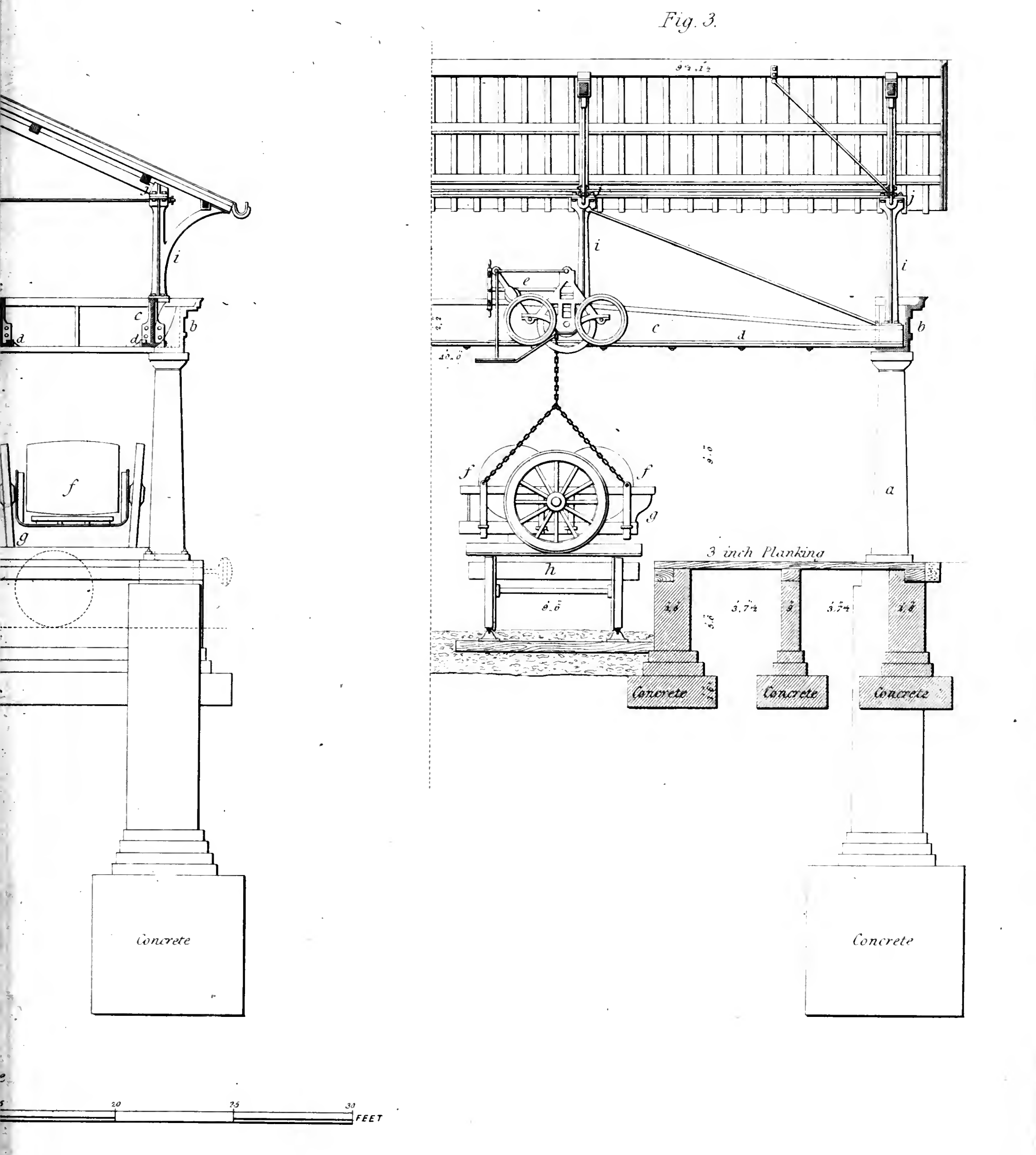
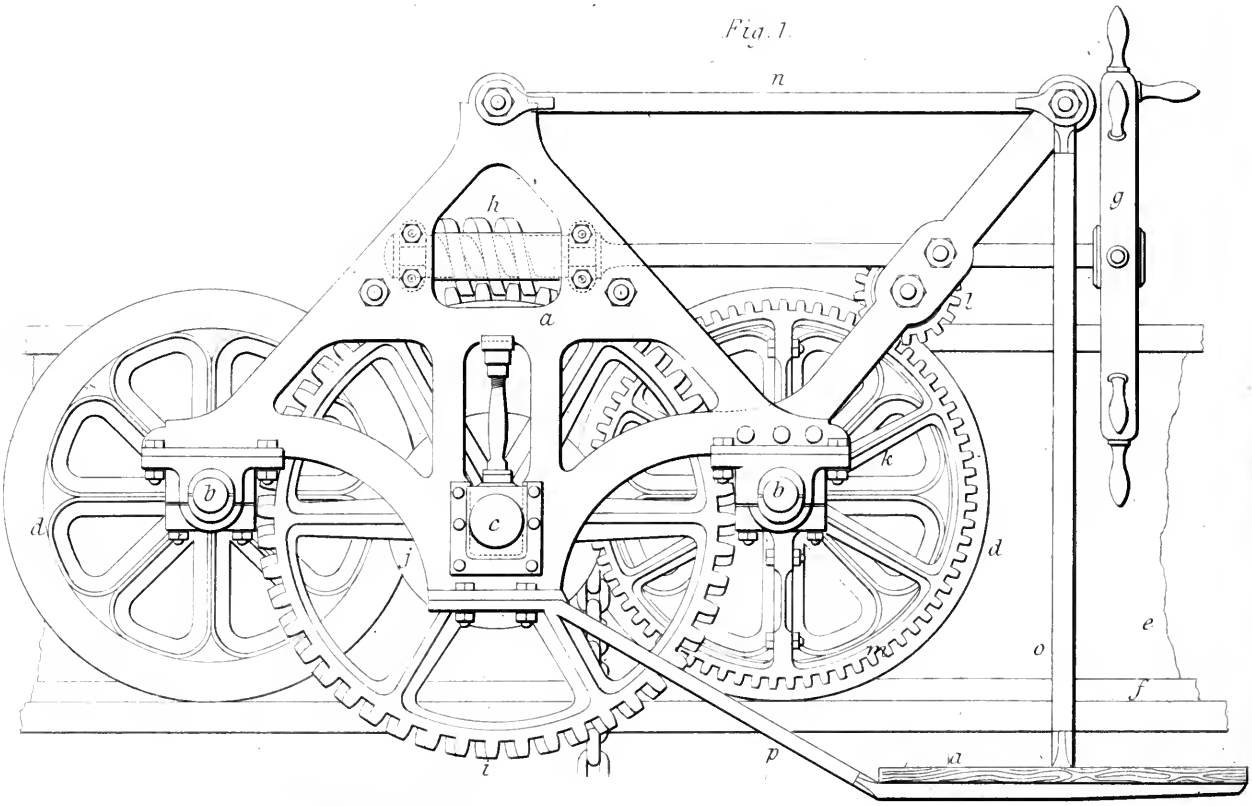


Fig. 3.
i
i
e
c
d
b
a
f
f
g
h
3 inch Planking
Concrete
Concrete
Concrete
Concrete
Concrete
20
25
30
FEET

le 1847.

Fig. 1.



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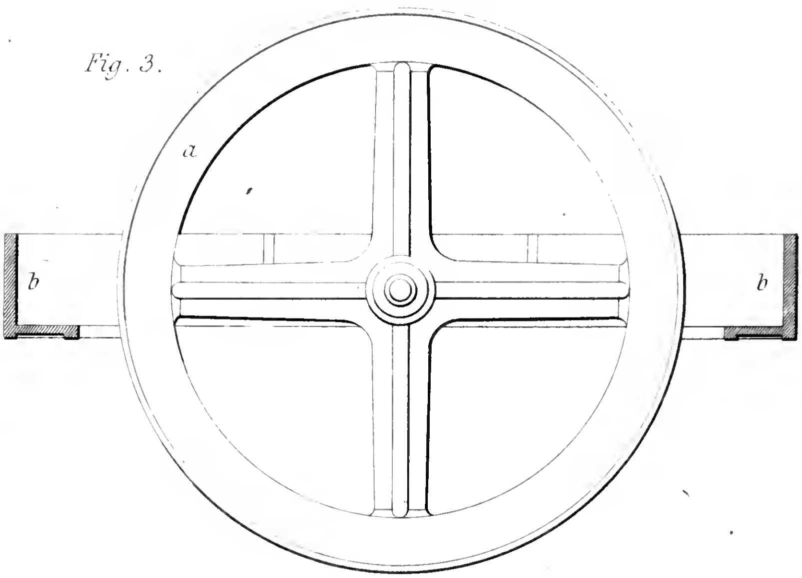


Fig. 6.

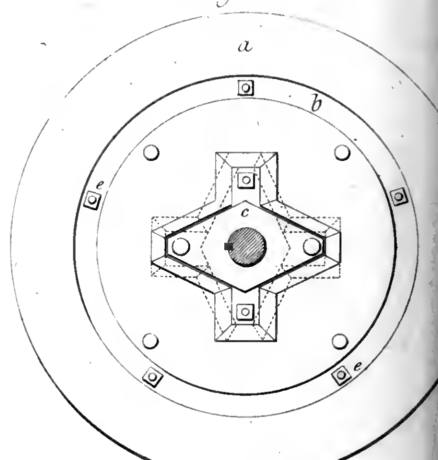


Fig. 4. Fig. 5.

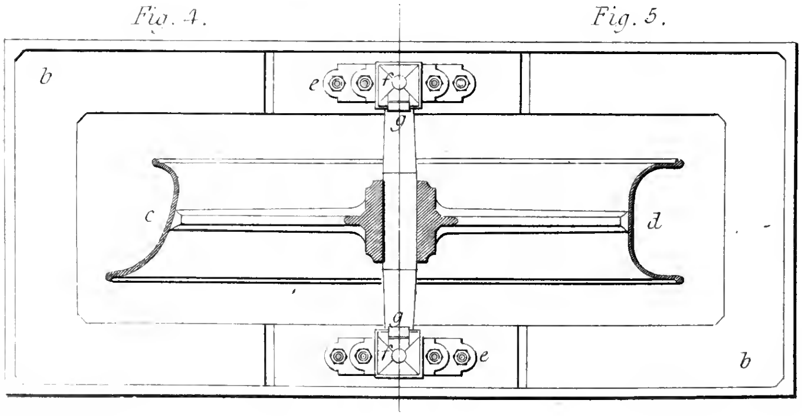
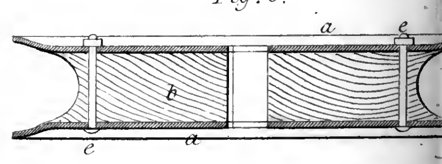


Fig. 8.



Scale

INS 12 9 6 3 0 1

G. D. Dempsey, del.

London

Fig. 2.

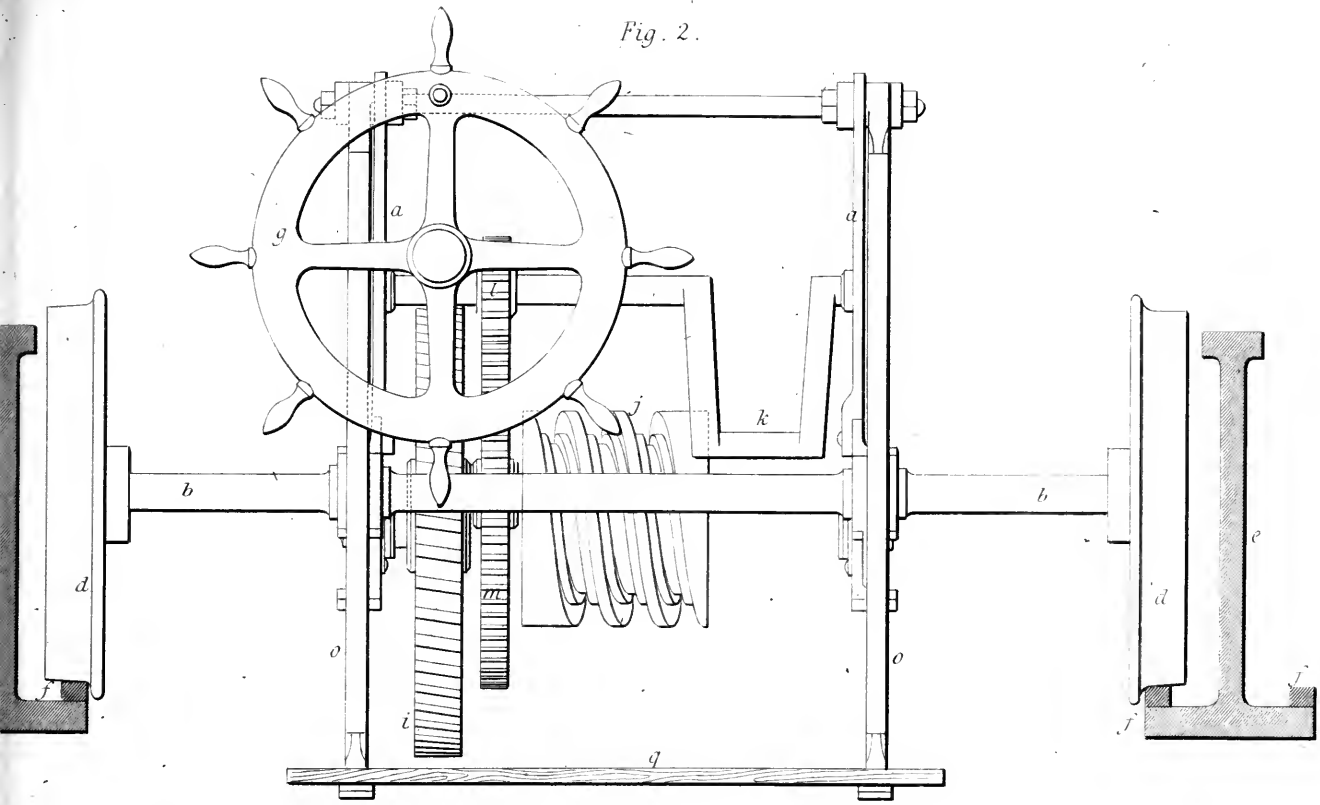


Fig. 7.

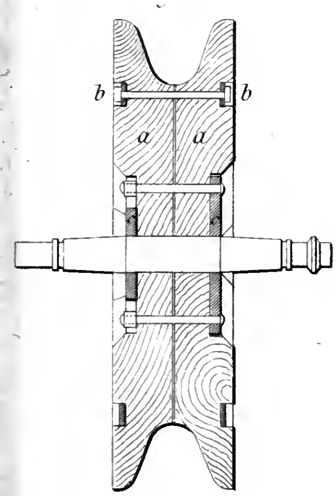


Fig 9.

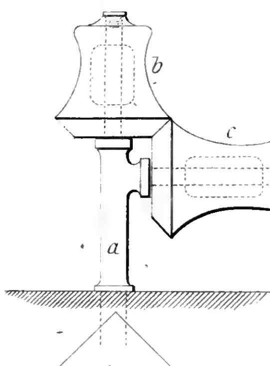


Fig. 11

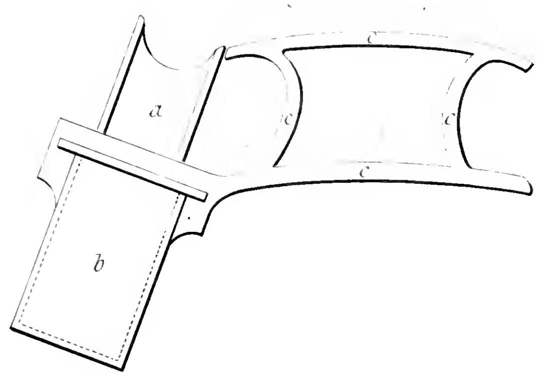


Fig. 10.

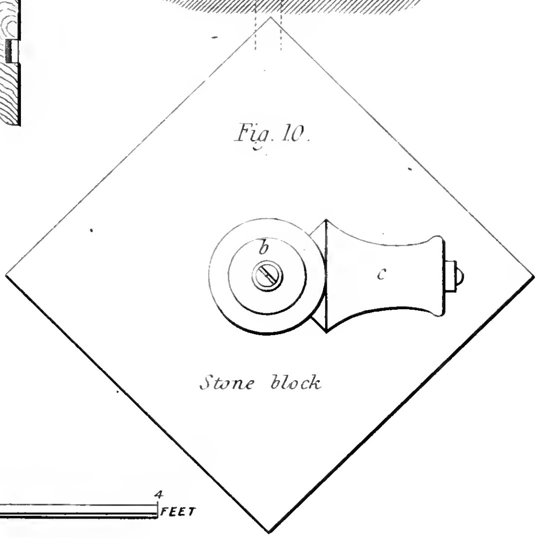


Fig. 12.

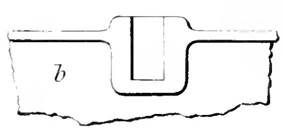
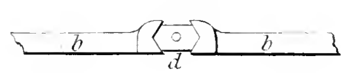
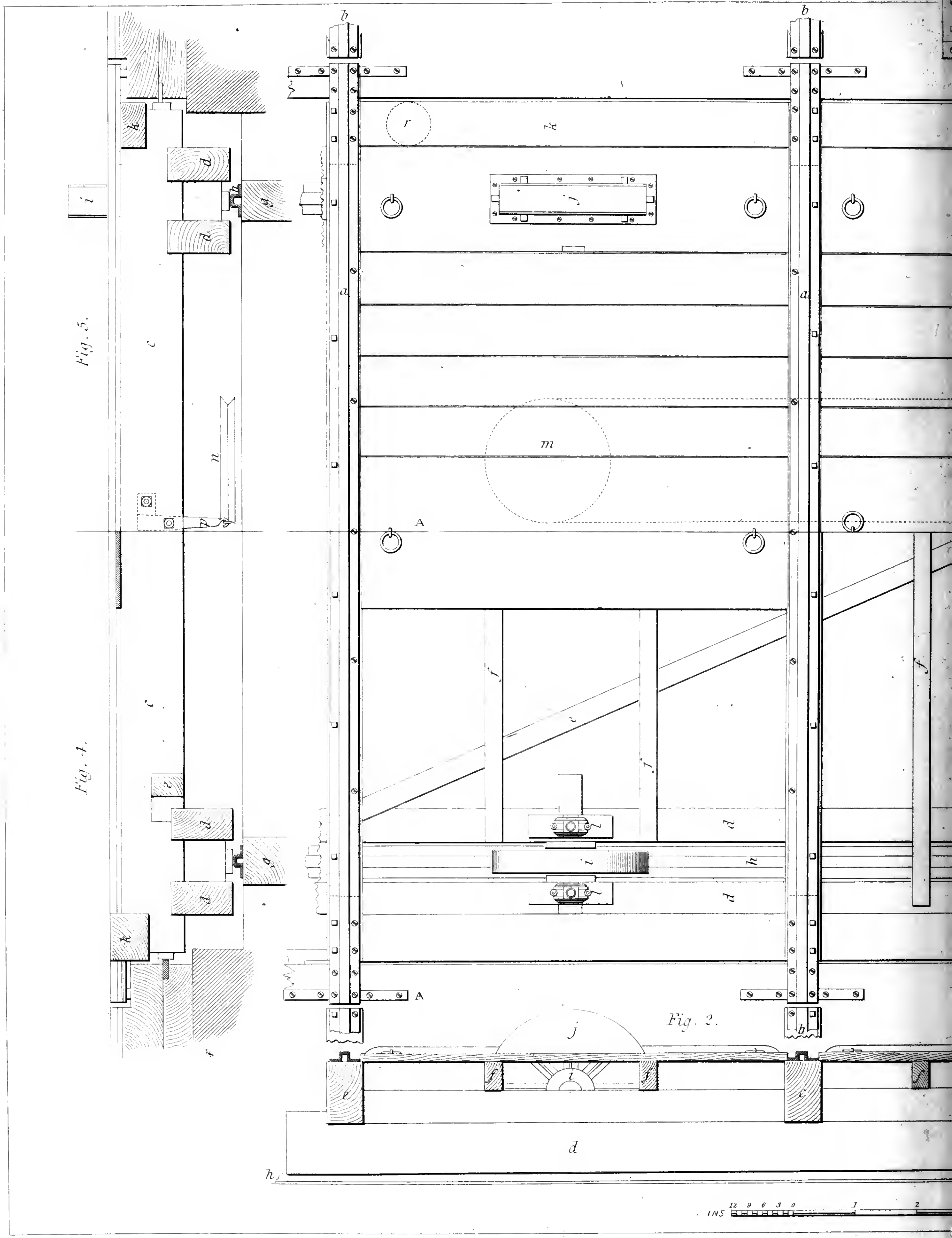


Fig. 13.



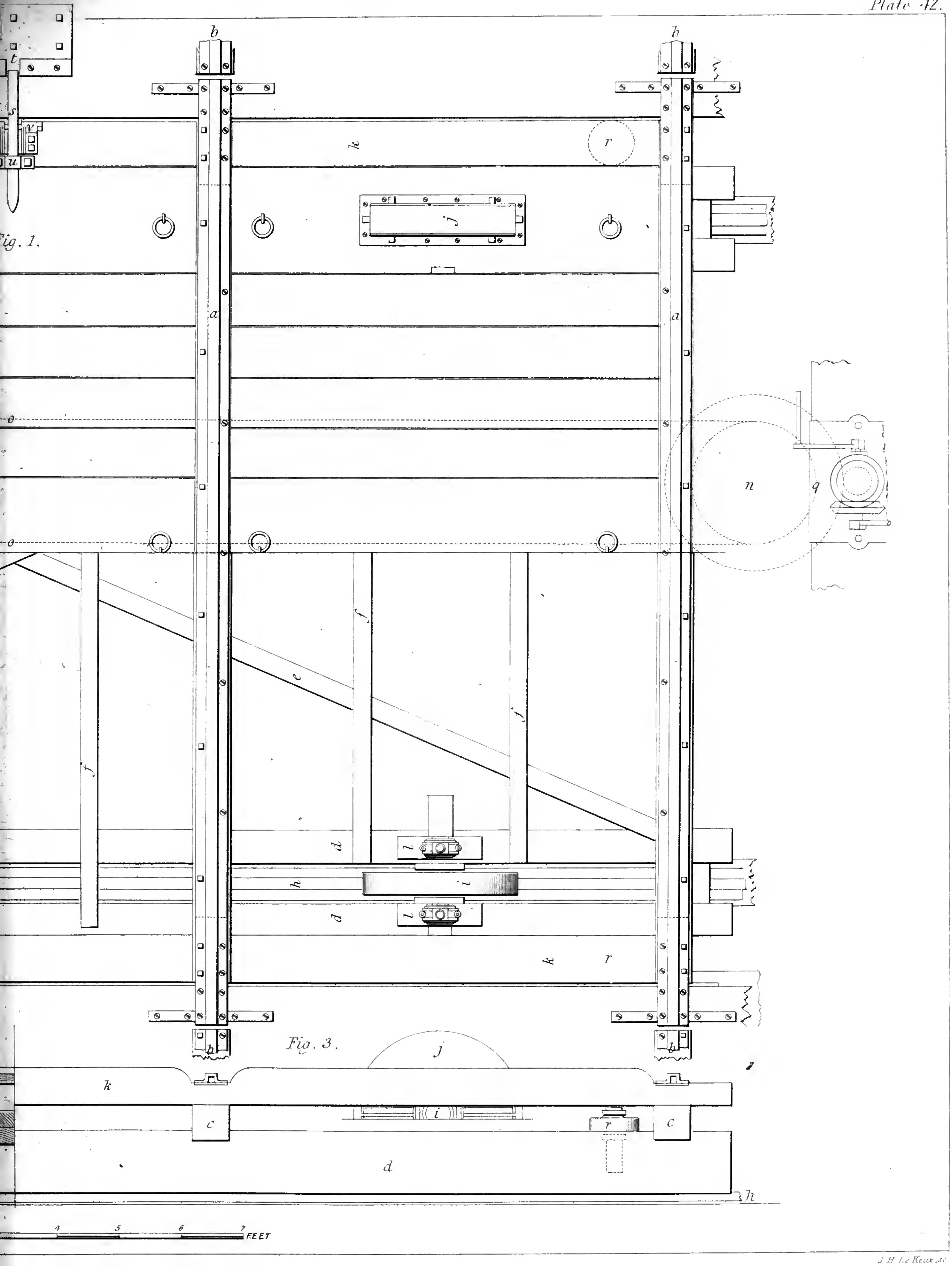
3 4 FEET

J. H. Le Keux sc.



G. D. Dempsey, del

London; Jo



J. H. Le Keux, sc.

Weale, 1847

Fig. 1.

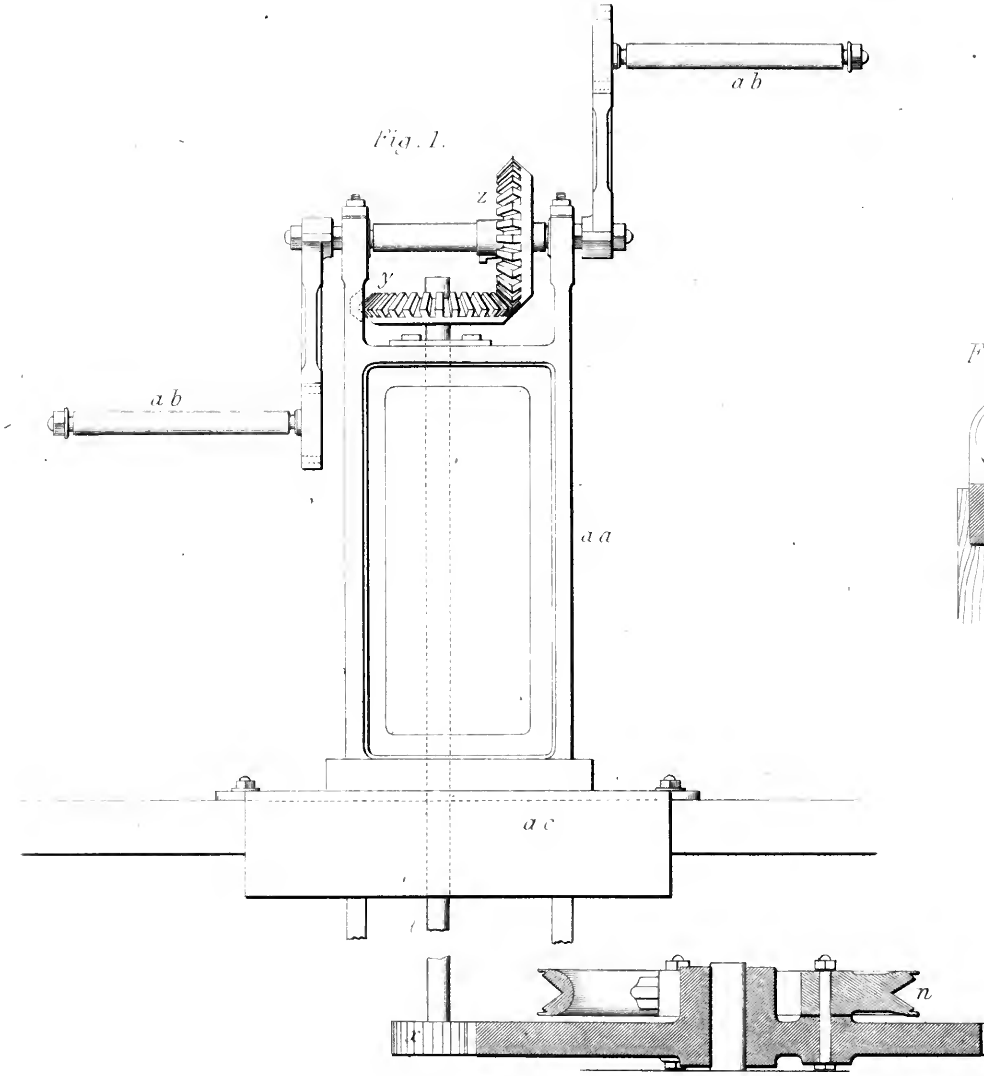
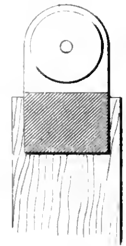


Fig. 8.



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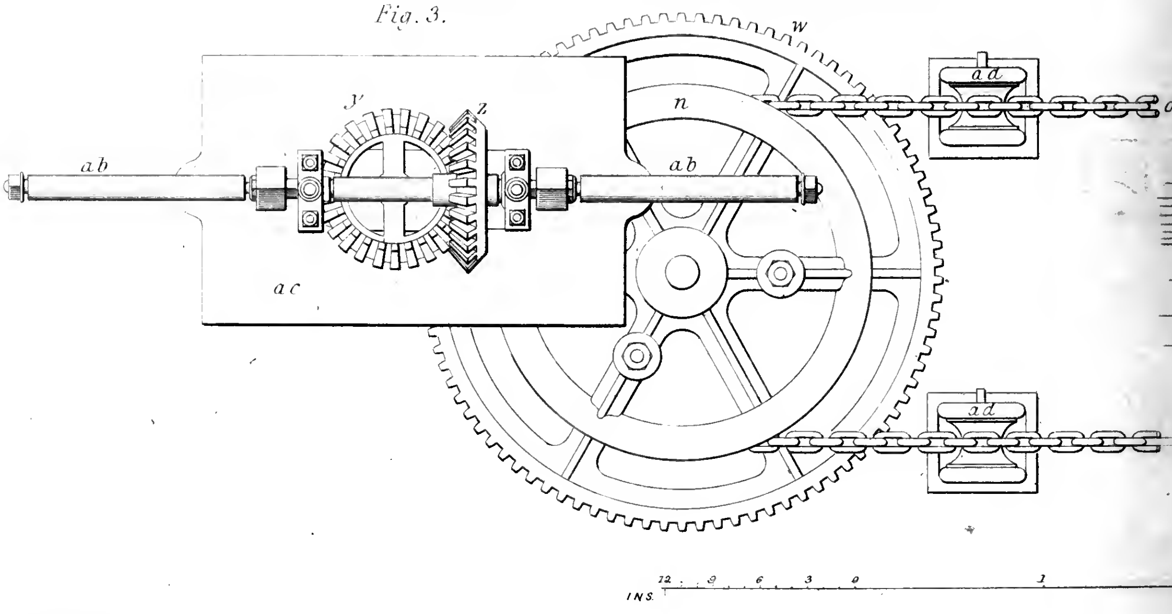

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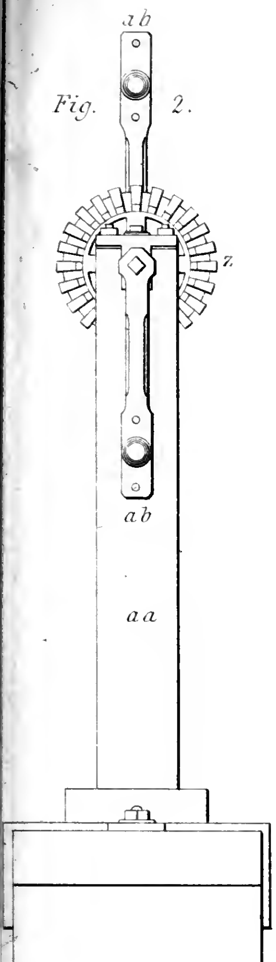
Fig. 2.



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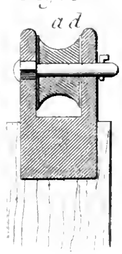

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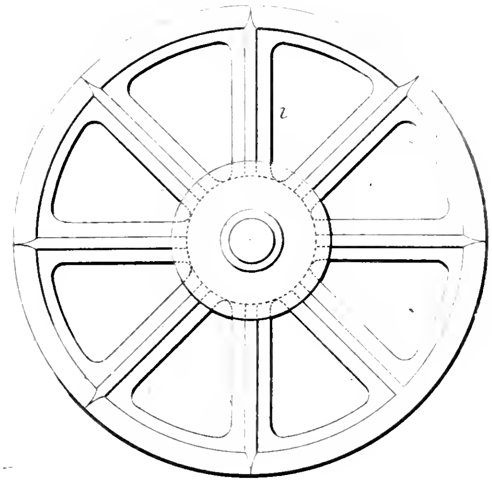

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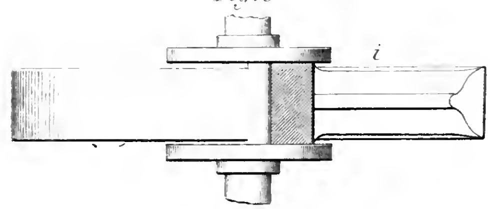

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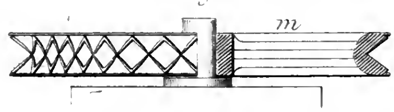

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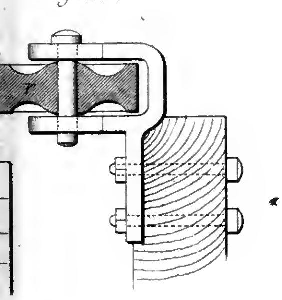

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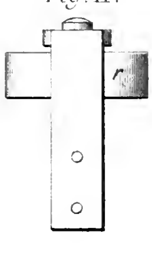

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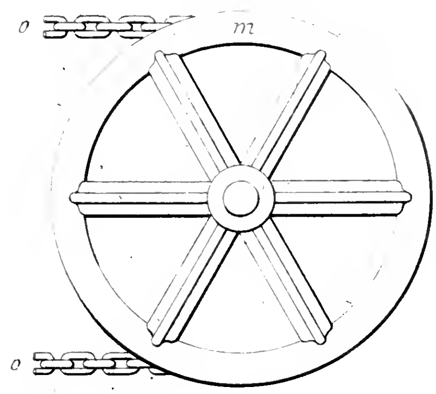

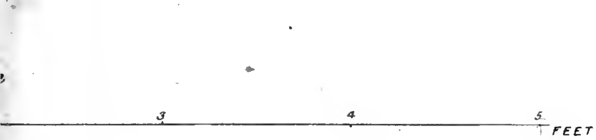

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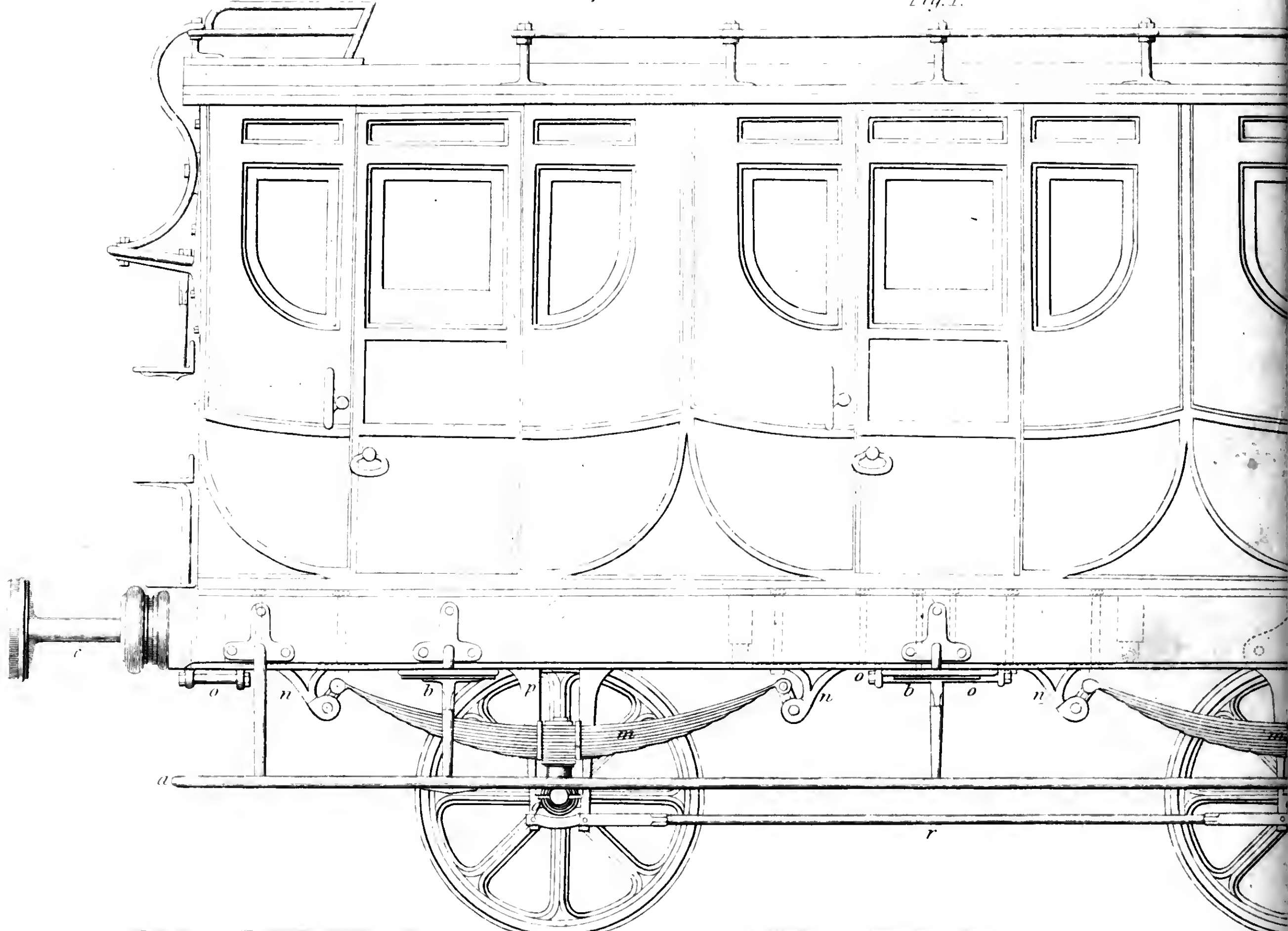

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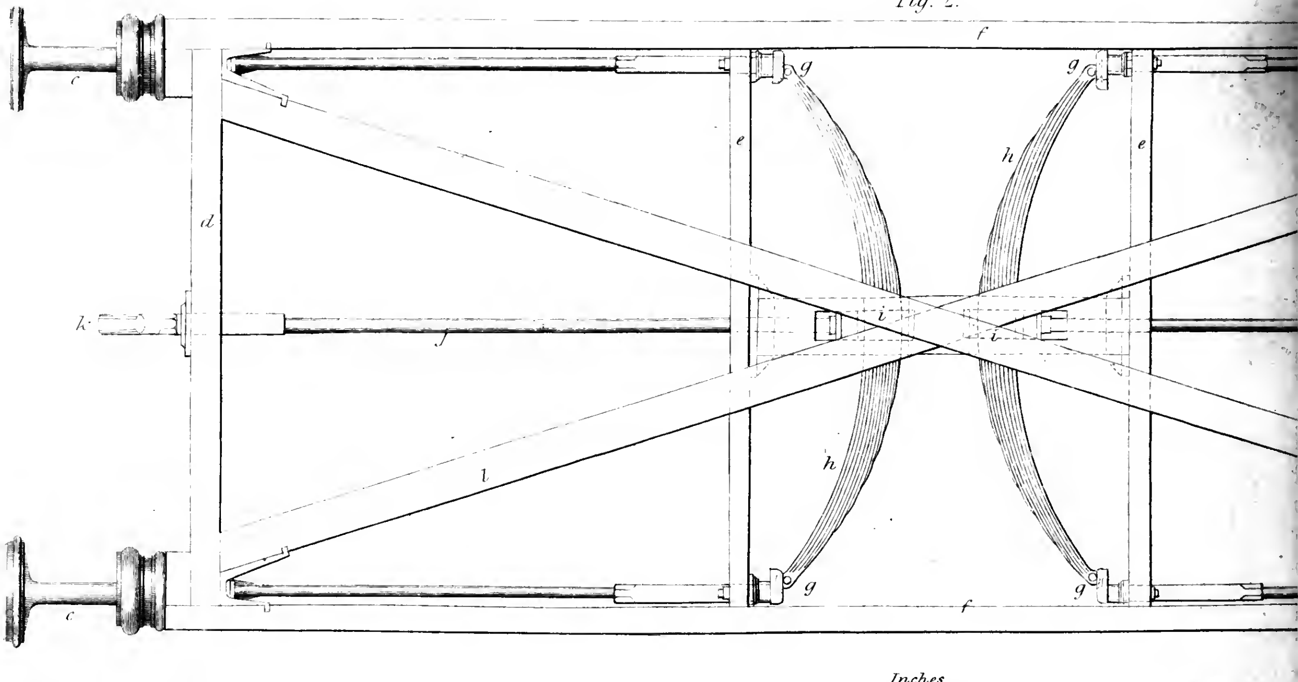

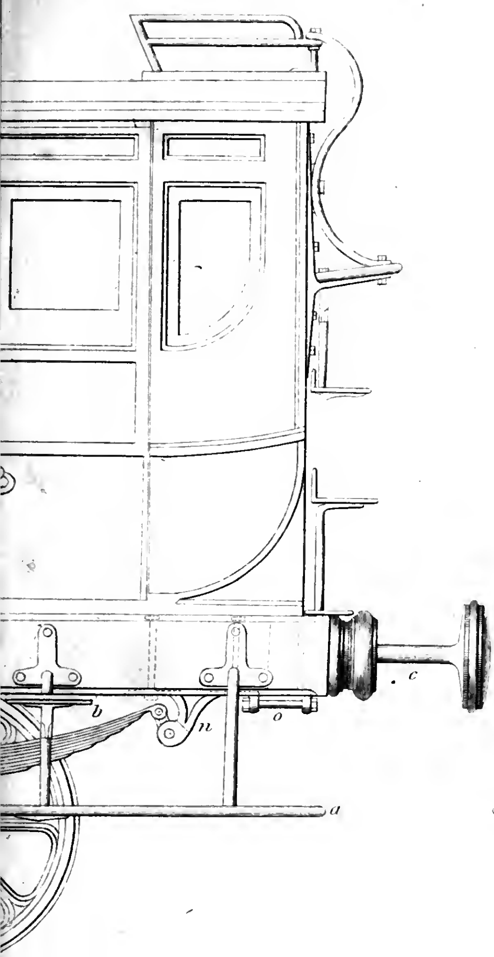

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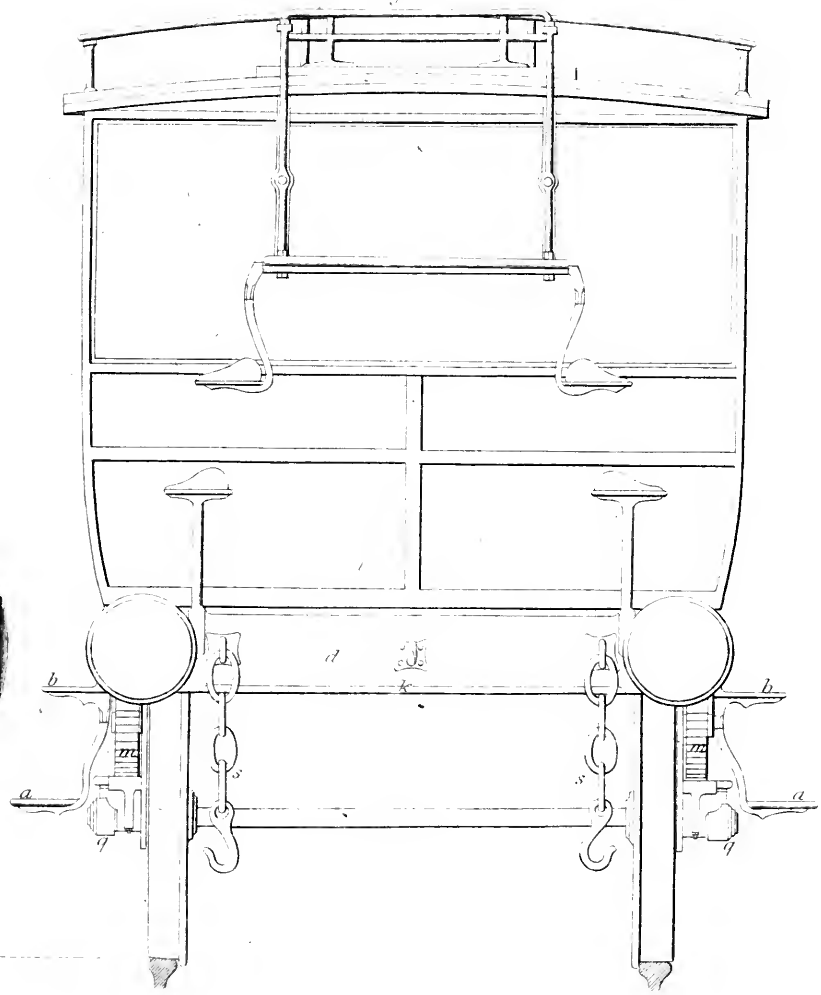

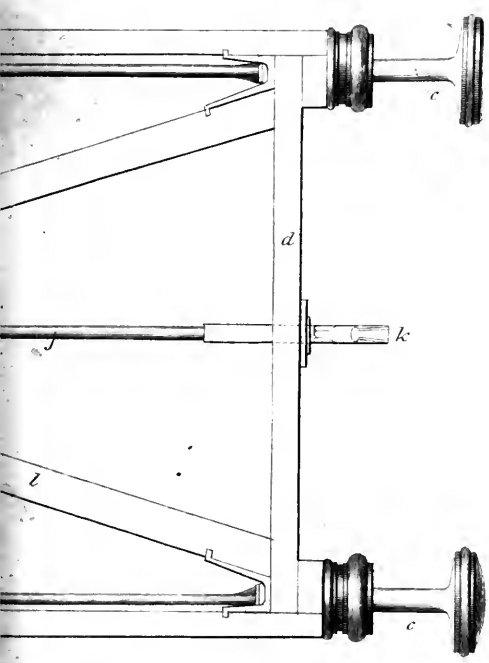

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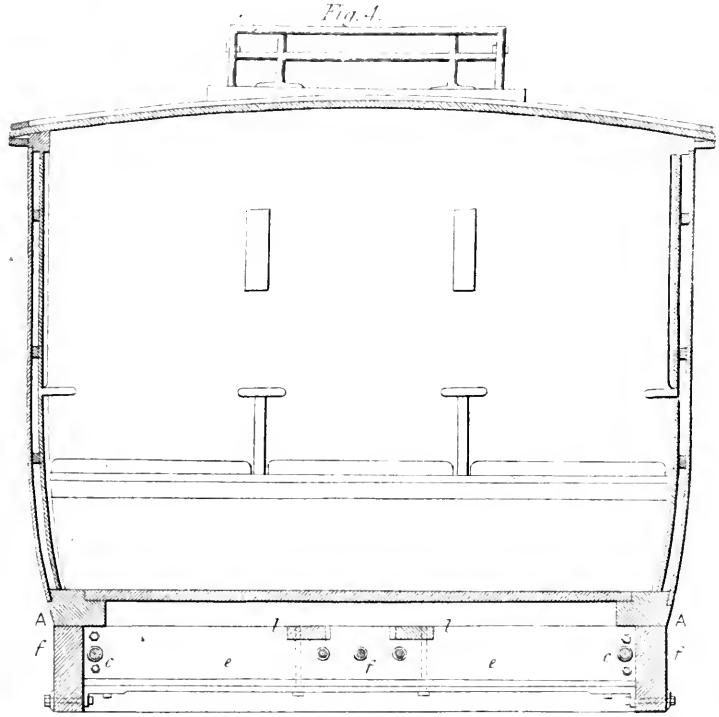

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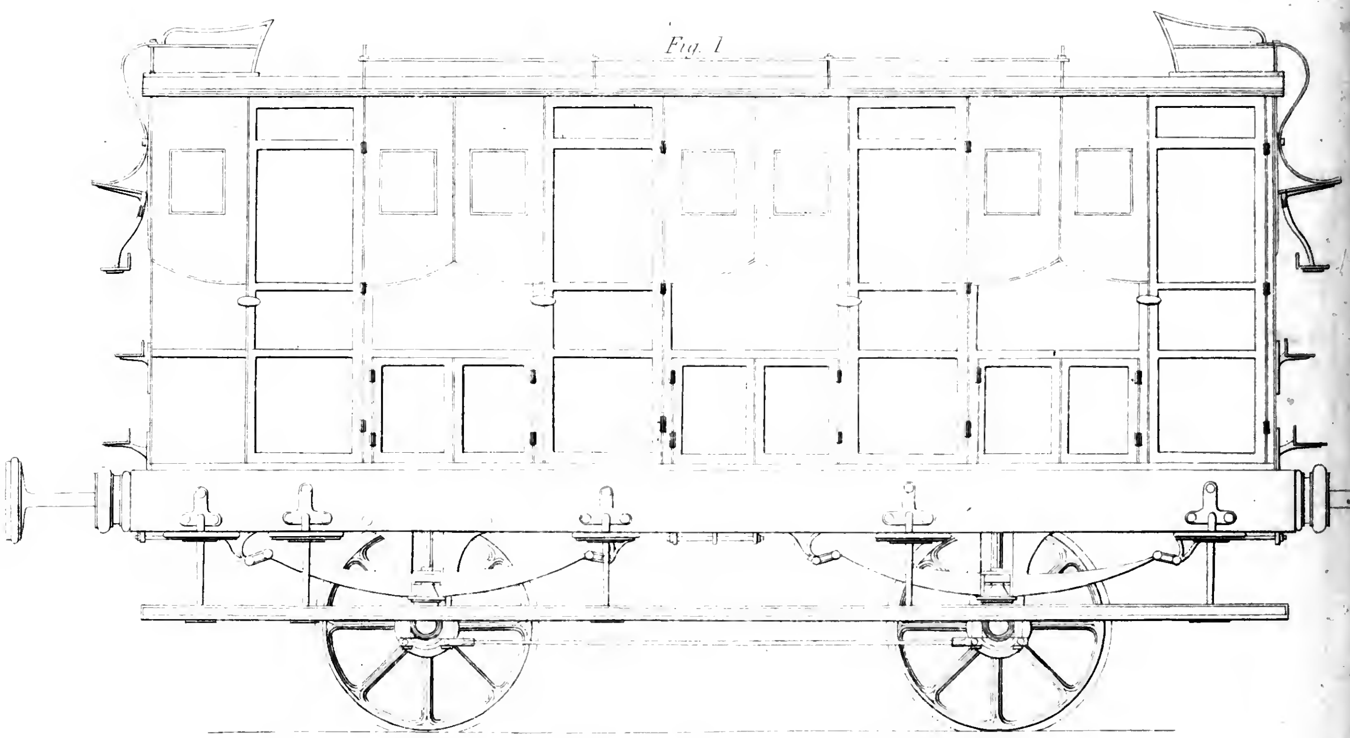
Fig. 1



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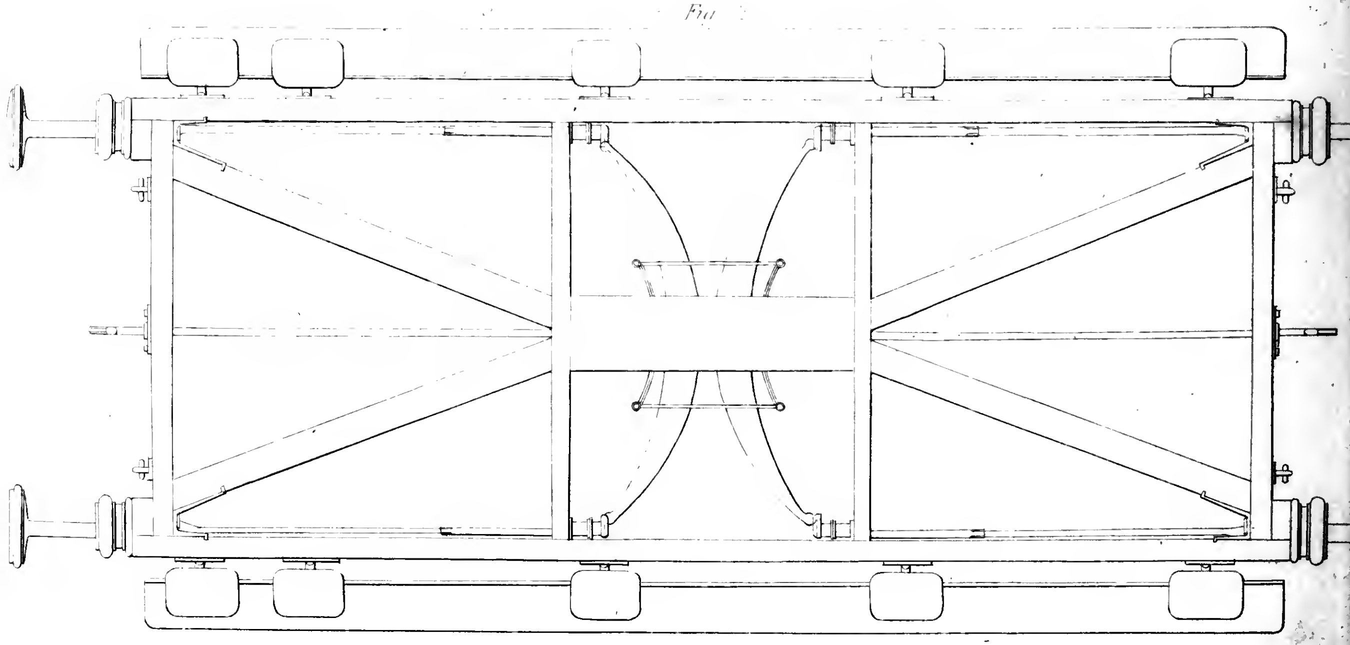

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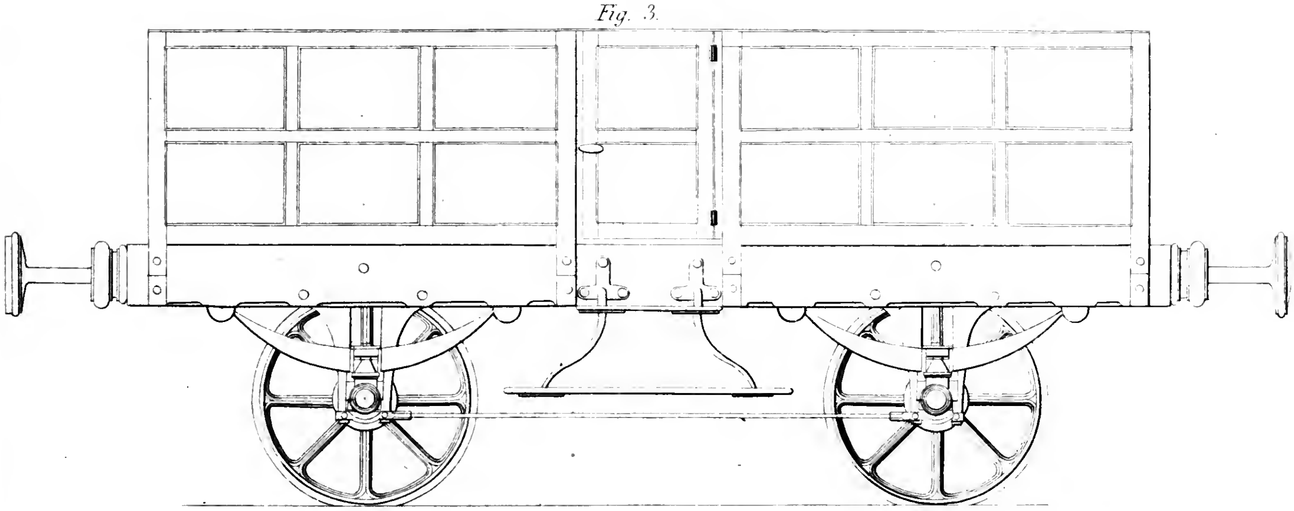
Fig. 3.



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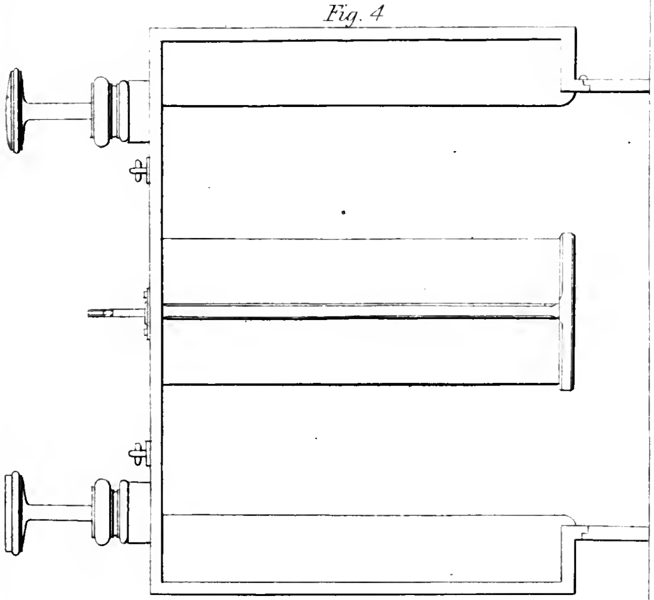

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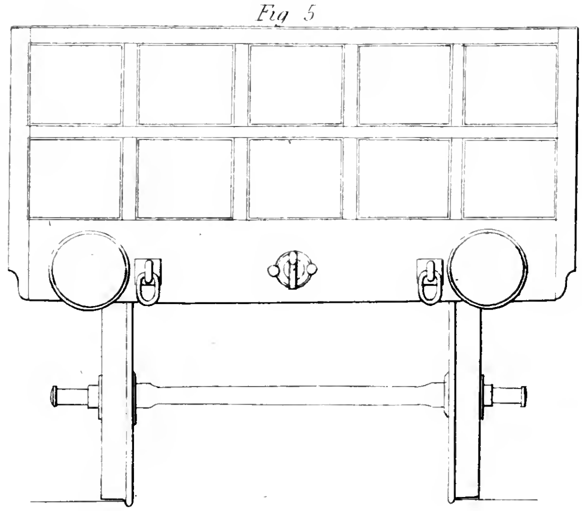

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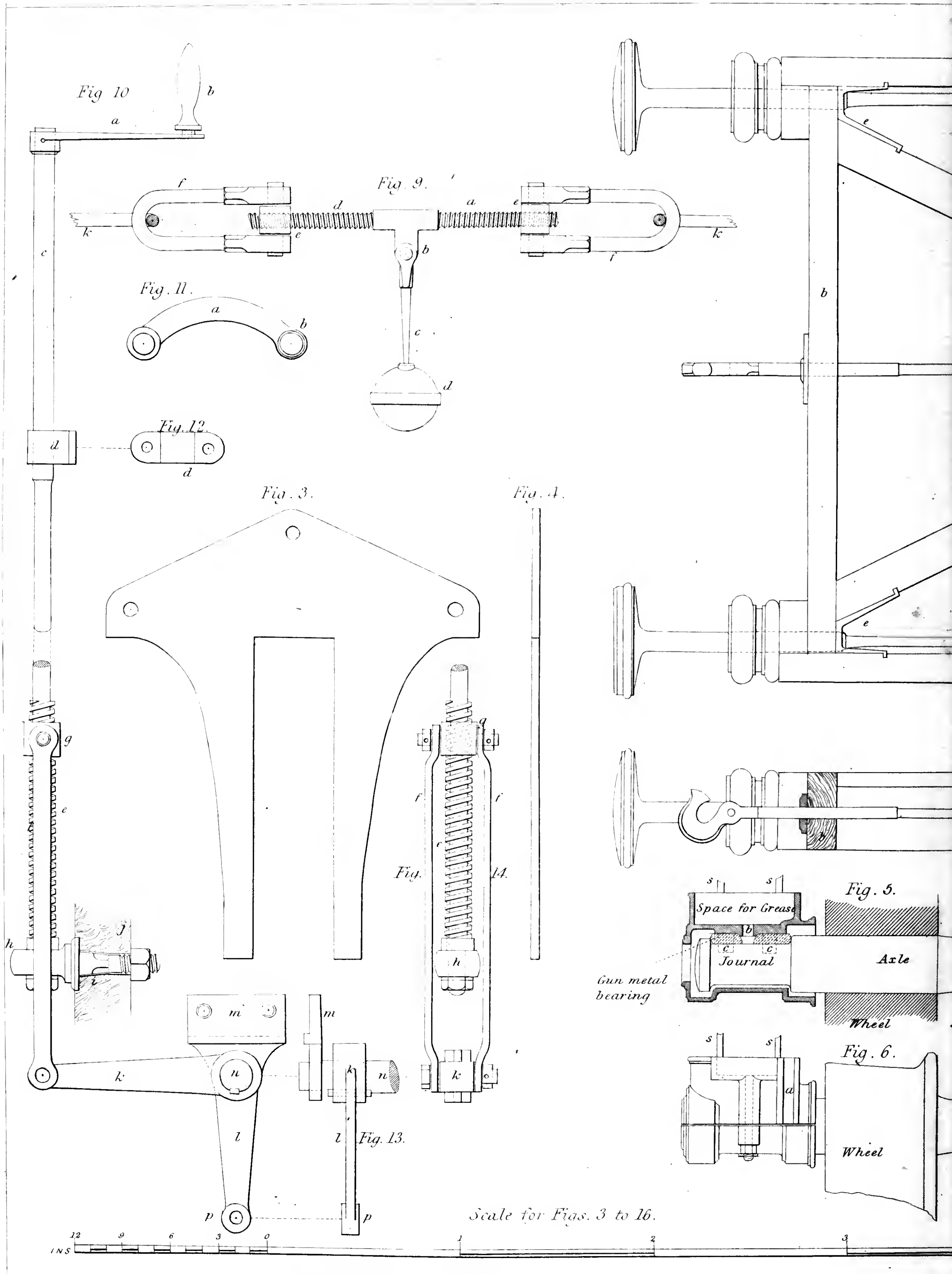

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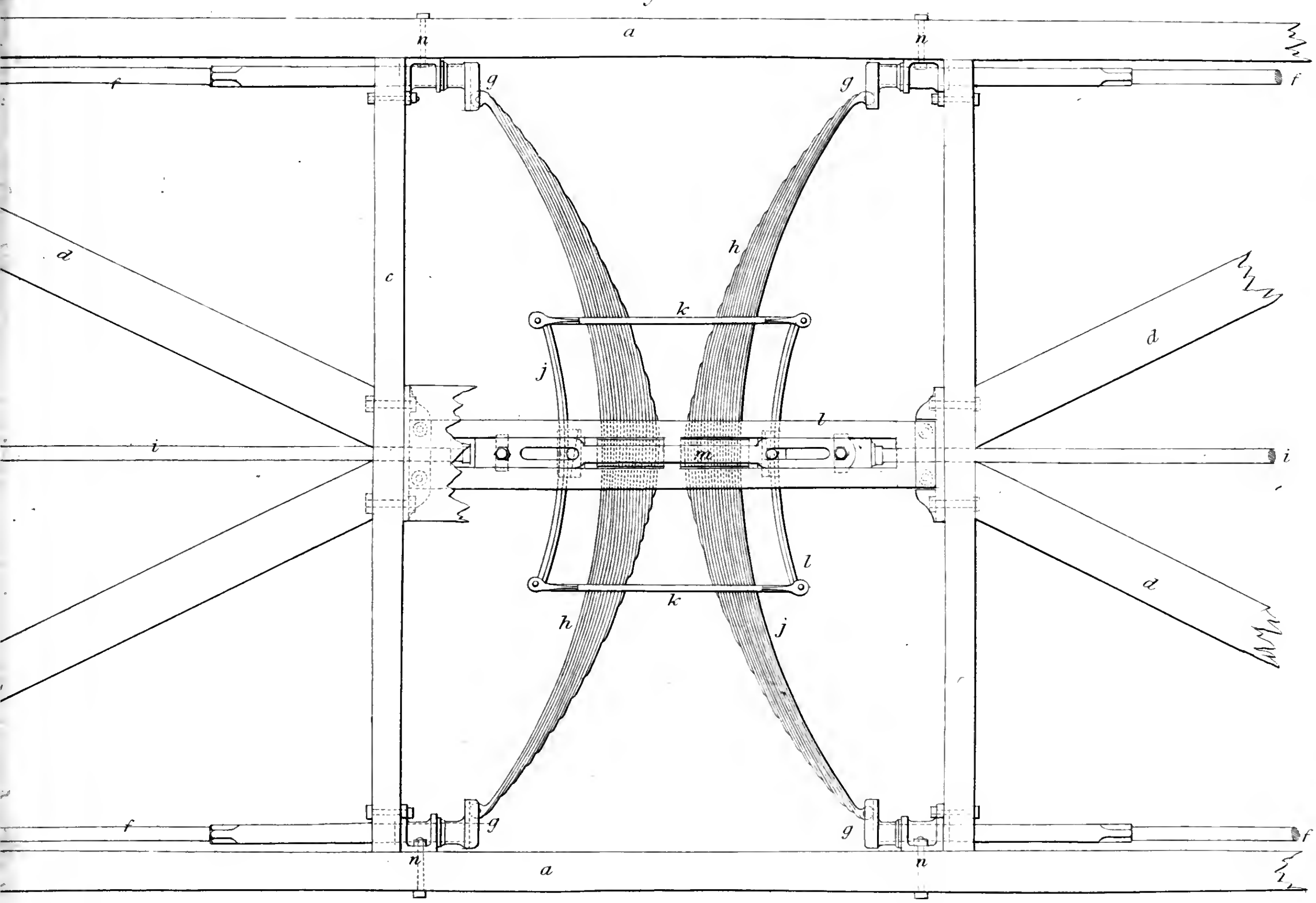

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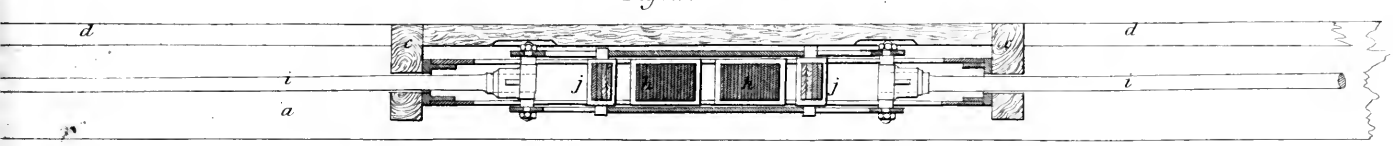

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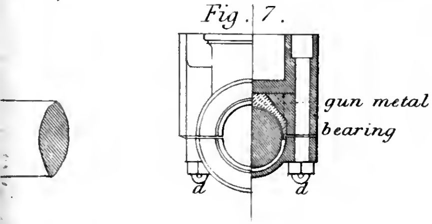

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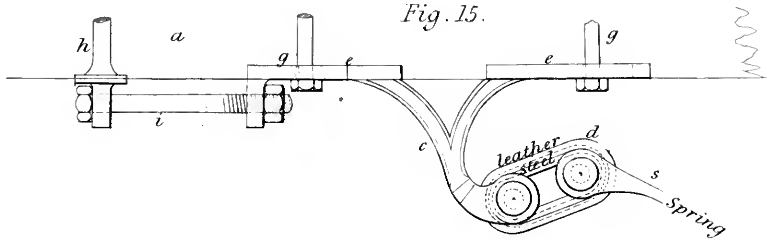

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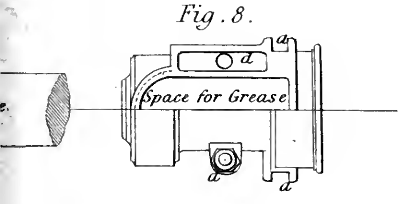

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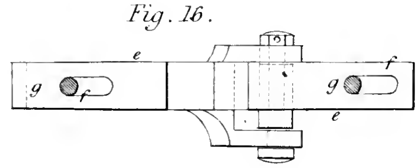
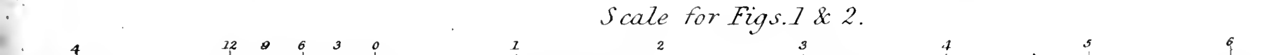


Scale for Figs. 1 & 2.



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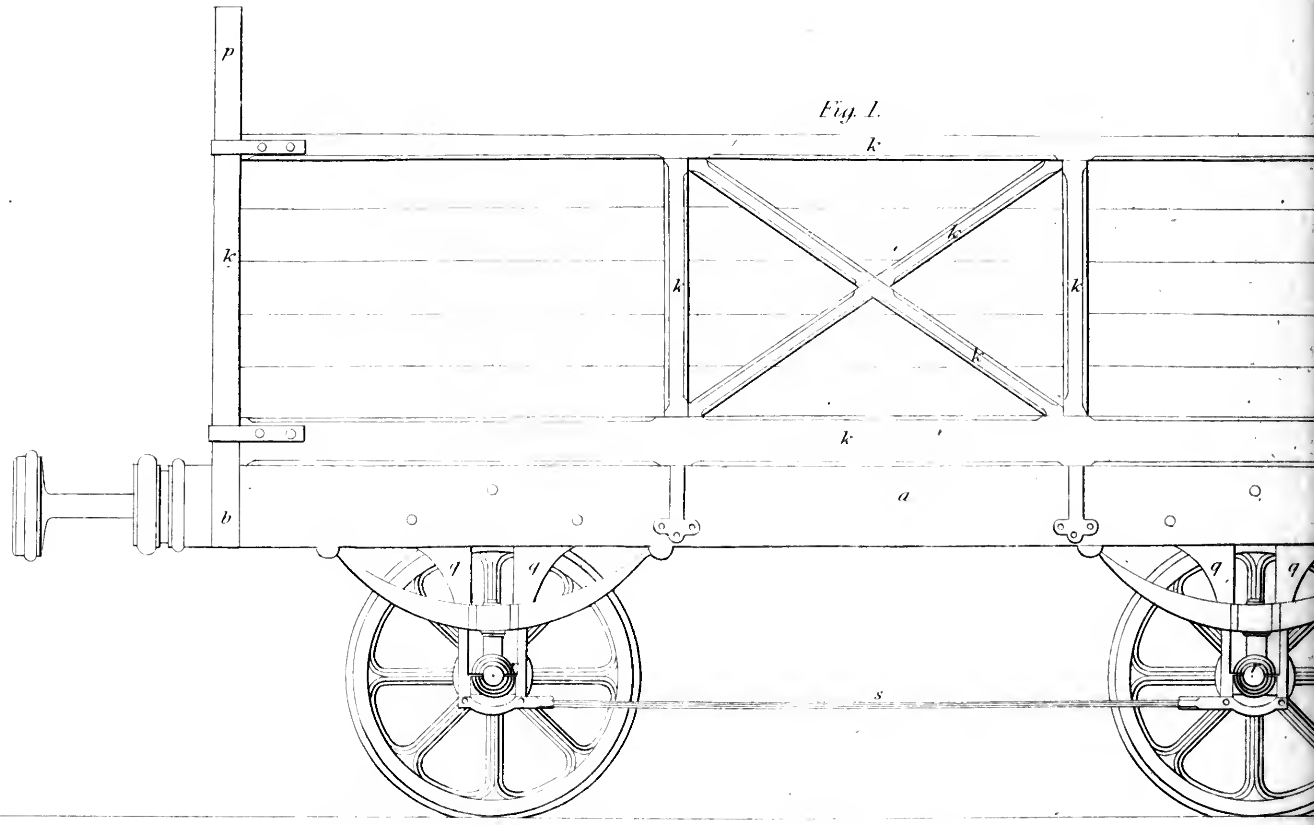

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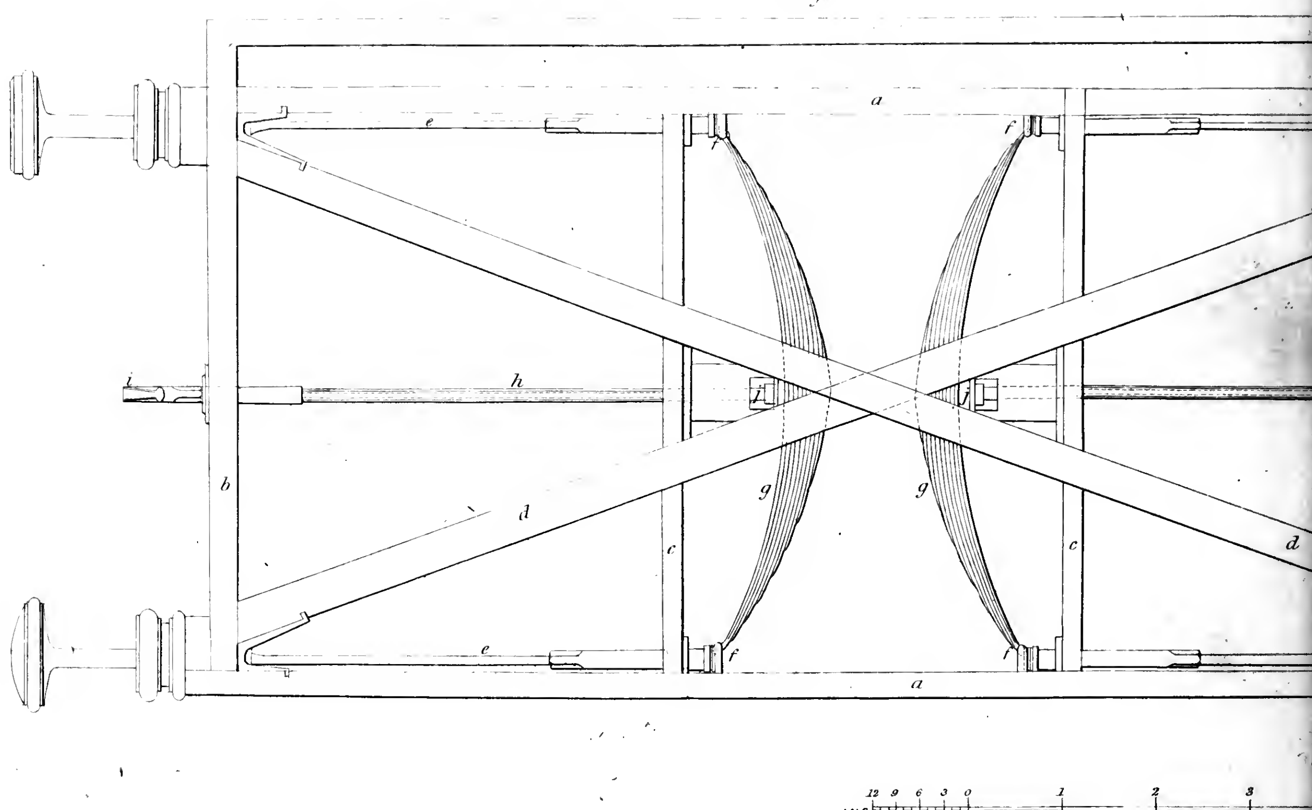

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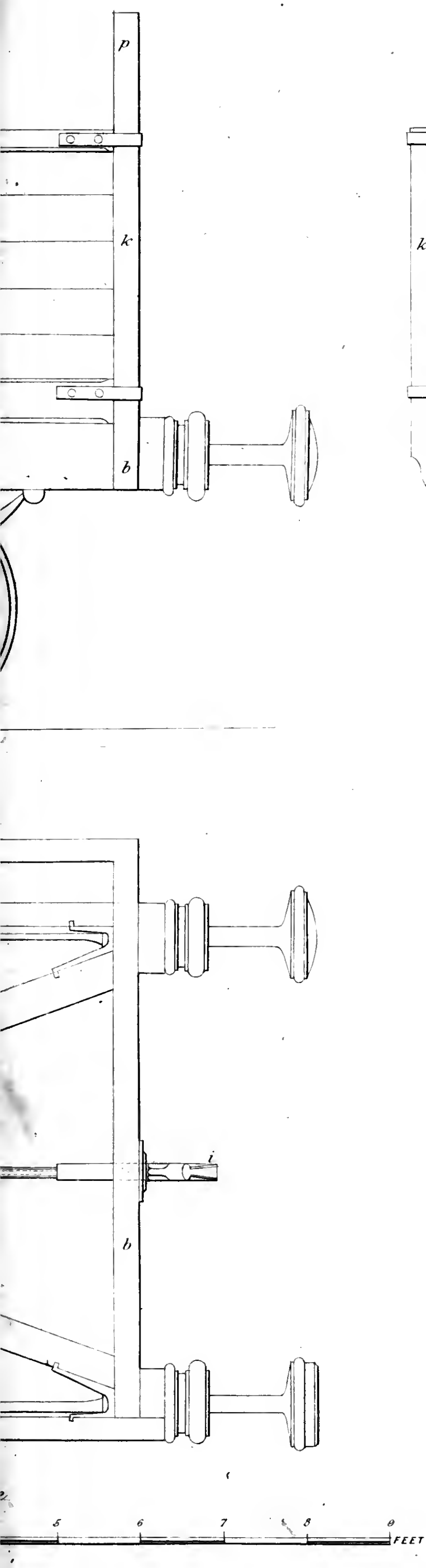

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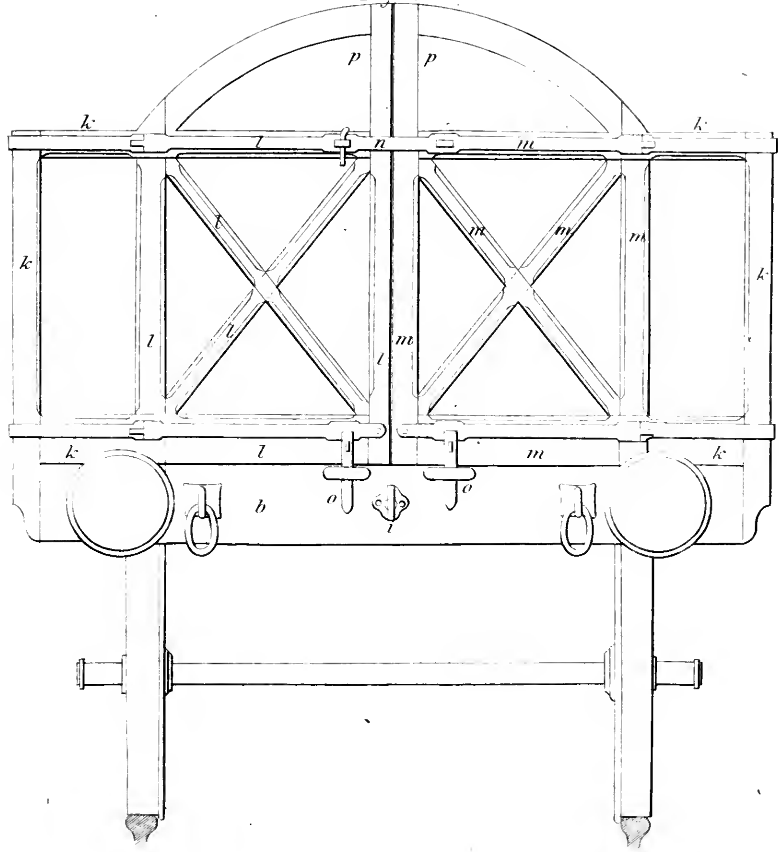

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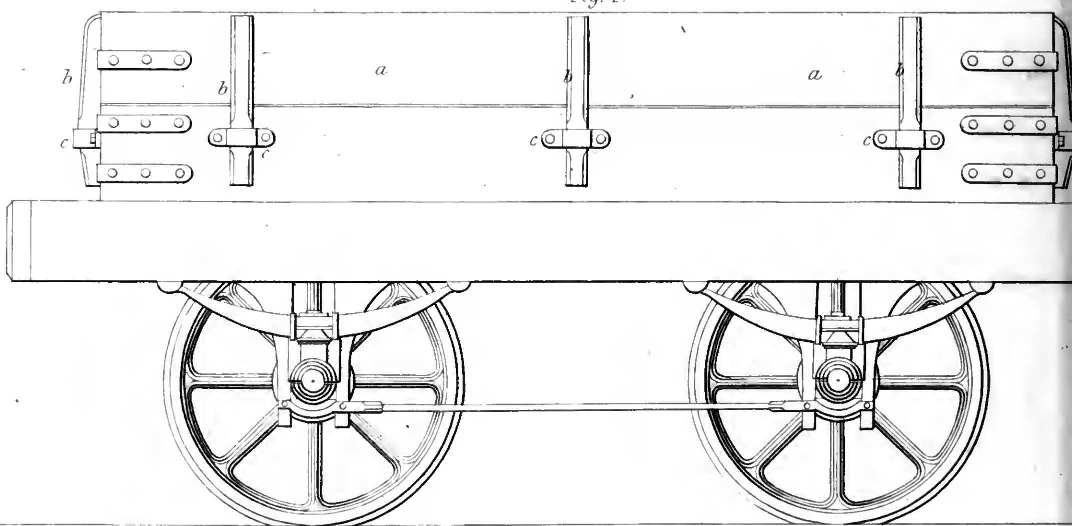

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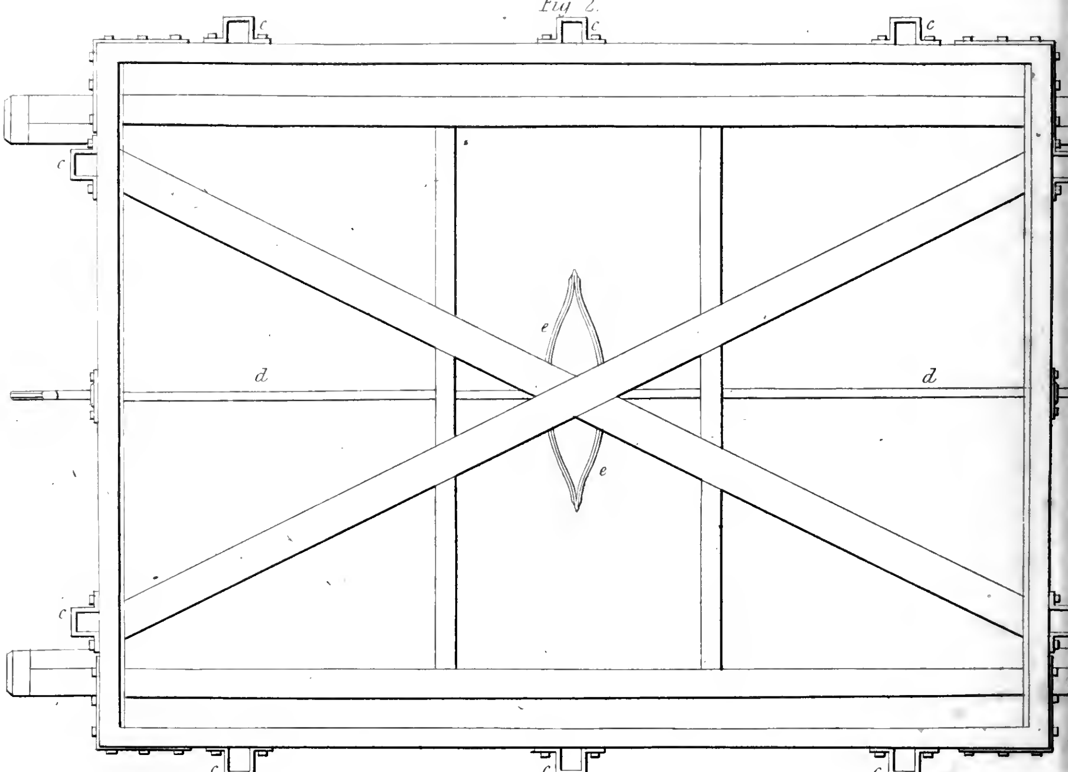

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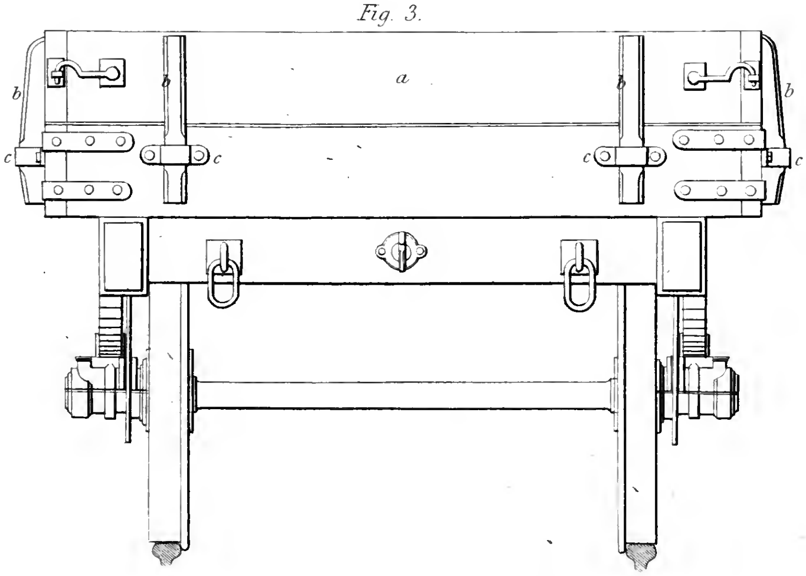

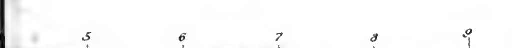

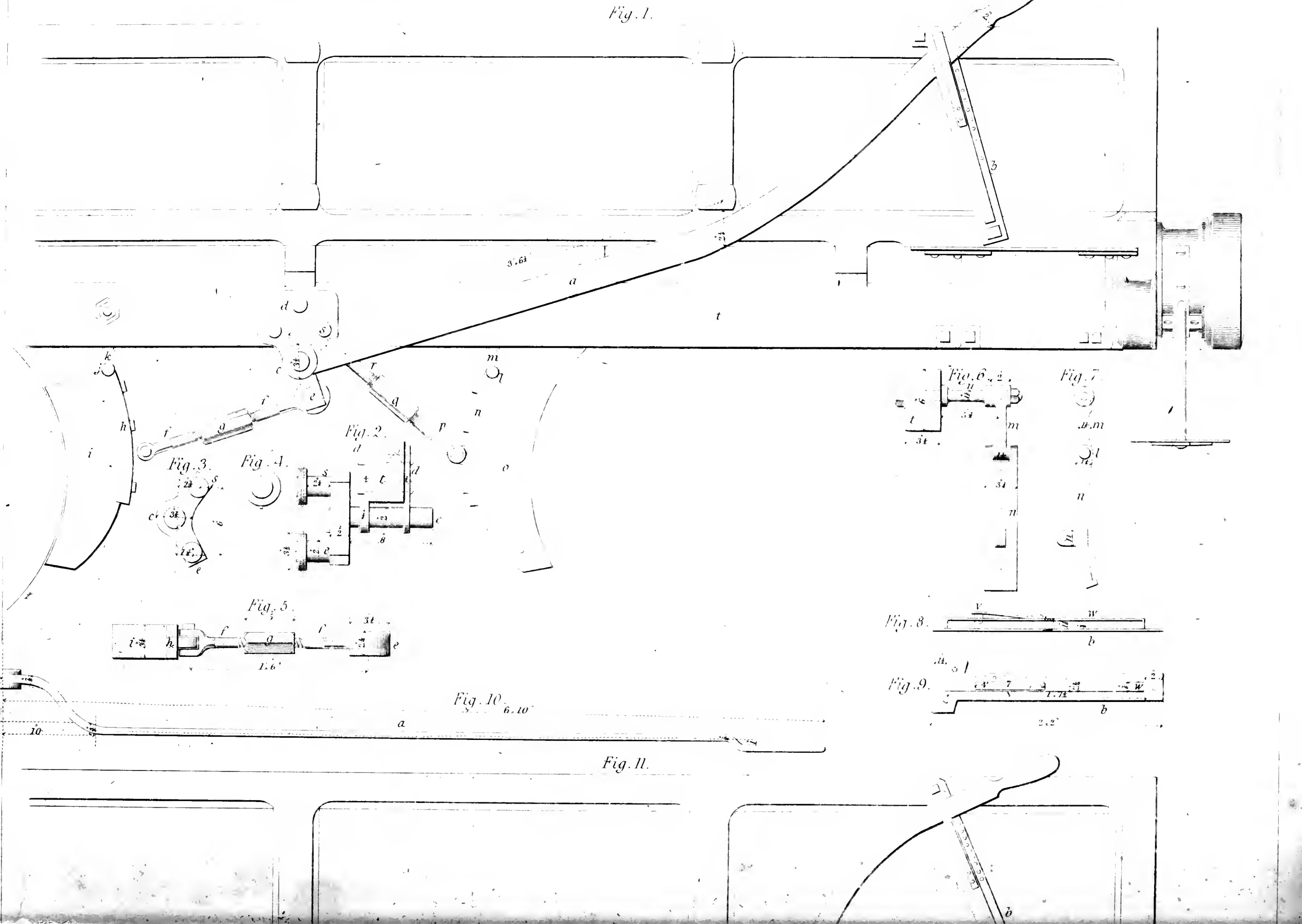
Fig. 1.
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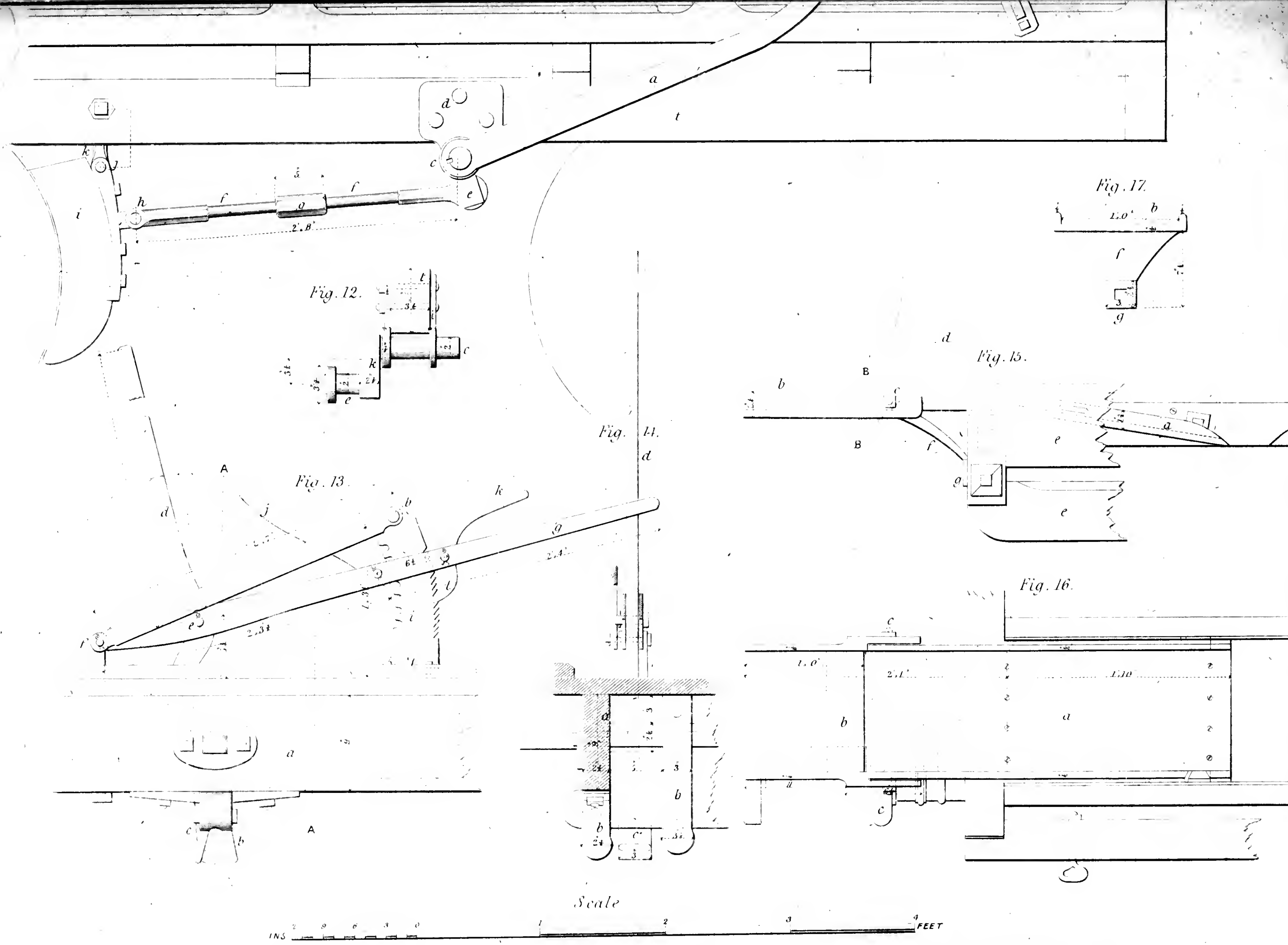

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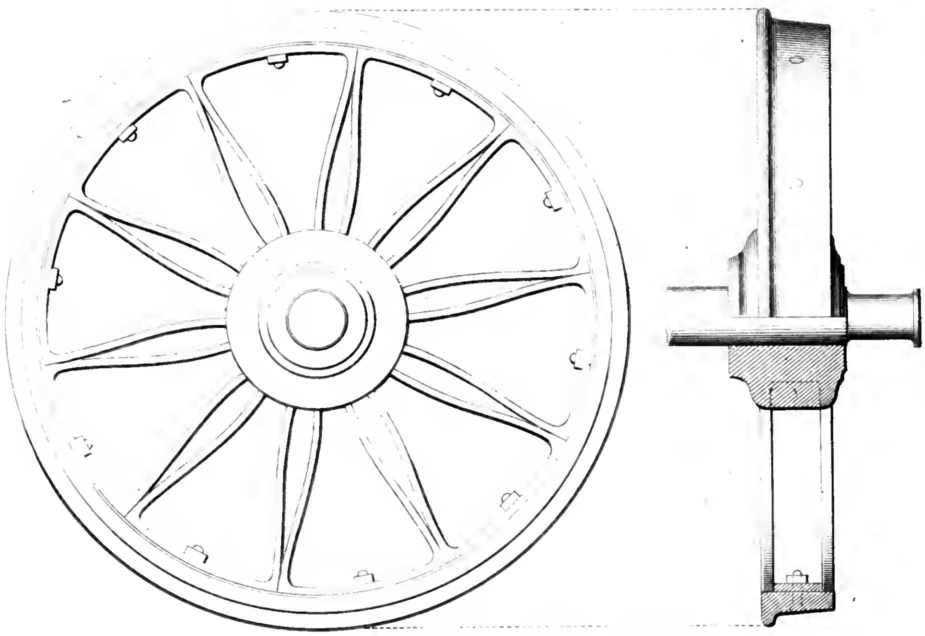

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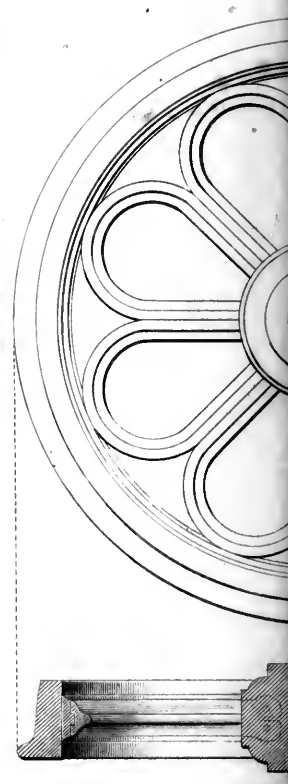

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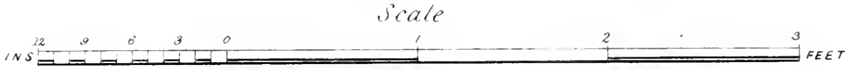

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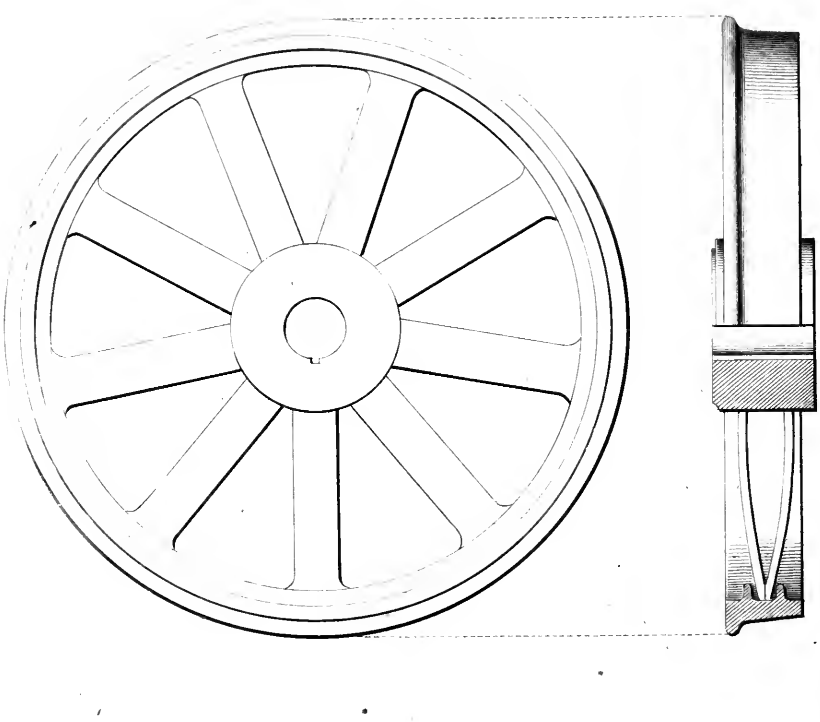

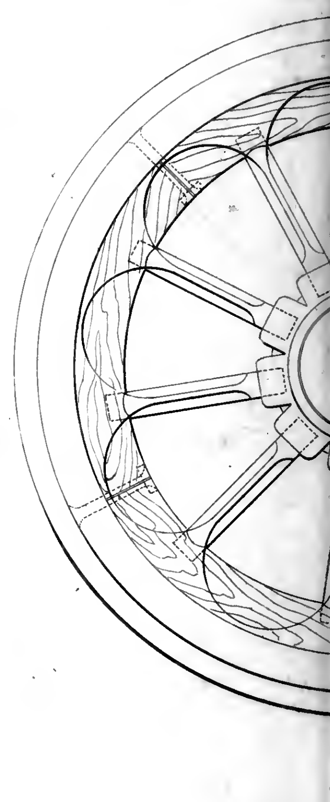

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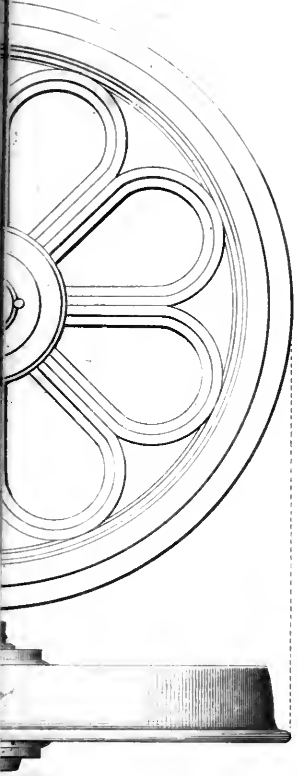

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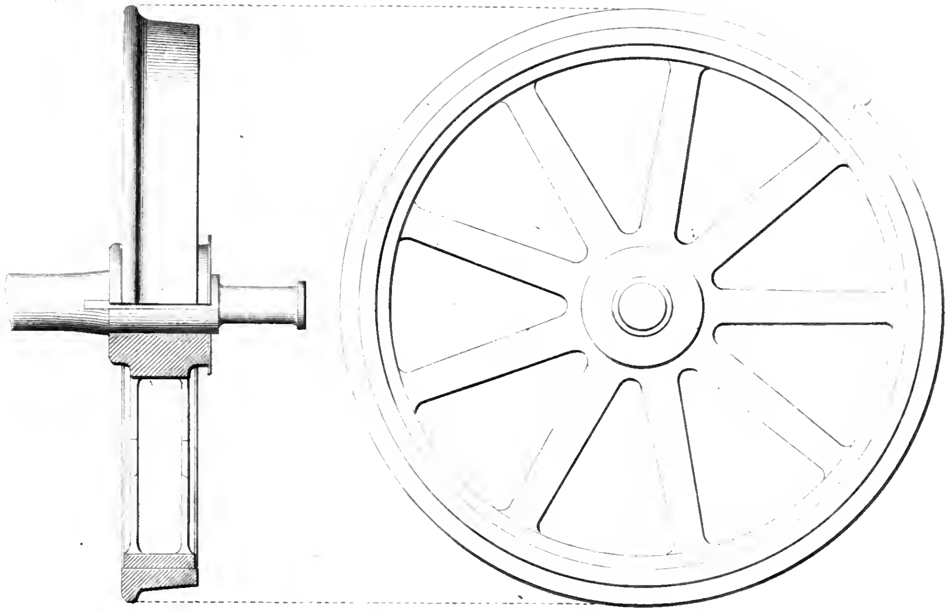

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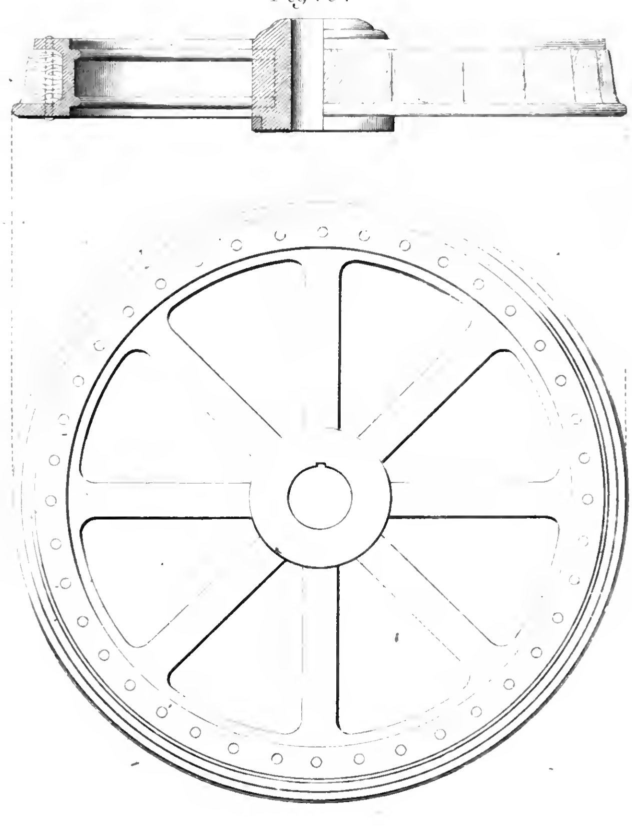

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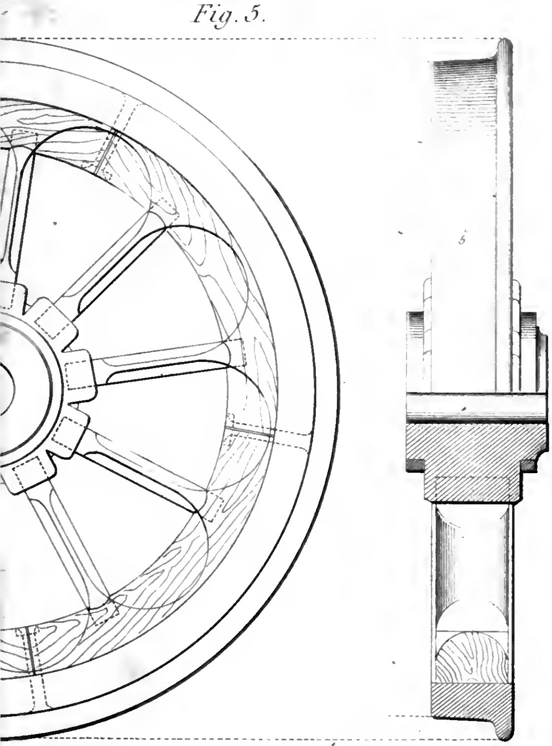

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